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CONTENTS

Semi-Popular Articles

The Water-Soluble Gums—Their Botany, Sources and Utilization 3
Turkish or Oriental Tobacco 32
Coir Dust or Cocopeat—A Byproduct of the Coconut 42
Grapes and Wine 46
Essential Oils—A Brief Survey of Their Chemistry and Production in the United States 71
The Importance of Plant Classification in Hevea 84
A Chemurgic Survey of the Desert Flora in the American Southwest 111
Production, in Venezuela, of Indigenous Varieties of Tobacco 132
The "Palo de Tomate" or Tree Tomato 140
Safflower 143
Cinchona Cultivation in Guatemala—A Brief Historical Review up to 1943 150
The American Peanut Industry 158
Production and Utilization of Alfalfa 170
Microbial Farming 184
Milkweed—A War Strategic Material and a Potential Industrial Crop for Sub-marginal Lands in the United States 223
Manicoba and Mangabeira Rubbers 240
World Production and Consumption of Millet and Sorghum 265
Plant Growth-Regulators 289
History, Taxonomy and Culture of the Pineapple 335
Mycological Production of Citric Acid—the Submerged Culture Method 360
Research on the Improvement of Turpentine Practices 375
Fiber Flax in Oregon 395
The Essential Oil of *Pectis papposa* 407
Problems Associated with the Procurement of Plant Products from the American Tropics 413
Irish Moss—A Seaweed that Supports an Industry 428

Technical Literature Reviews

Roselle—A Potentially Important Plant Fiber 89
Watermelon Breeding 193
Forest-Tree Genetics Research—*Populus* L. 299

Utilization Abstracts

Soybeans 41
Margarine 45
Flax 70
Newsprint from Wheat Straw 83
Essential Oils 104
Cannery Residues 106
Peanuts in Africa 107
Jojoba 131
Yerba Maté 139
Chlorophyll 142
Drug Plants of Africa 149
Vegetable Oils of Venezuela 157
Pecan By-products 169
Hardwood Pulp 192
Chemurgic Utilization of Wood 213
Hyoscine and Hyoscyamine 215
Cocona 216
Cedarwood Oil 217
Wormwood 219
Cottonseed 219
Bamboo Paper Pulp 239
Bamboo Blowgun 239
Cortisone from Yams 288
Waxes and Fats from Sugarcane 331
Flax 359
Citrus Waste Oil 374
Rutin 394
Carob 406
Papaya 406
Rice Hulls 412
Tall Oil 427
Safflower 427
Herculin 427
Indigenous Food Plants of West Africa 436
Tropical Woods 444

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VOL. 3 JANUARY–MARCH, 1949 NO. 1

Semi-Popular Articles

THE WATER-SOLUBLE GUMS—THEIR BOTANY, SOURCES AND UTILIZATION. *C. L. Mantell* 3

TURKISH OR ORIENTAL TOBACCO. *Frederick A. Wolf* 32

COIR DUST OR COCOPEAT—A BYPRODUCT OF THE COCONUT. *E. P. Hume* 42

GRAPES AND WINE. *A. J. Winkler* 46

ESSENTIAL OILS—A BRIEF SURVEY OF THEIR CHEMISTRY AND PRODUCTION IN THE UNITED STATES. *A. J. Haagen-Smit* 71

THE IMPORTANCE OF PLANT CLASSIFICATION IN HEVEA. *Richard Evans Schultes* 84

Technical Literature Review

ROSELLE—A POTENTIALLY IMPORTANT PLANT FIBER. *Julian C. Crane* 89

Utilization Abstracts

By the Editor

Page 41—Soybeans. *Page 45*—Margarine. *Page 70*—Flax. *Page 83*—Newsprint from Wheat Straw. *Page 104*—Essential Oils. *Page 106*—Cannery Residues. *Page 107*—Peanuts in Africa.

The Water-Soluble Gums—*Their Botany, Sources and Utilization*[1]

Arabic, tragacanth, ghatti, karaya and other commercially valuable gums are exudations of a variety of trees and shrubs in many parts of the world. Their hydrophilic and other properties render them useful in the adhesives, beverage, cosmetic, paint, papermaking, pharmaceutical, textile and other industries.

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Terminology

The term "water-soluble gums" embraces a group of substances, all of which are derived from plants, either directly or indirectly, the property of which to form viscous adhesives, jellies or pastes by absorption of or dispersion in water has earned a place for them in the arts and industries. The term, however, is a misnomer, for the substances are not soluble in the strictly scientific sense, as are salt, sugar and other crystallizable materials. Gums are not crystalloids, but colloids, and as such are strictly amorphous and do not have melting point, freezing point or boiling point characteristics. The designation "water-soluble" serves to distinguish true gums, in a technical sense, from the many other substances to which the term "gum" is also commonly applied but which are not water-soluble and which differ from true gums also in other important respects. These other substances are gum damar, gum copal, gum congo, gum kauri and Manila gum, all of which are resinous, non-water-soluble exudations from plants. In a somewhat related manner the so-called gum-resins, which are mixtures of hydrophilic and hydrophobic constituents, include gum benzoin, gambier, catachouc, gamboge, guaiac, kino, myrrh, storax and the balsams of Peru and Tolu. Addition of dragon's blood completes this listing of commercially important gum-resins which, although designated "gums" in commerce, are not hydrophilic but are closely related to the resins.

Physical Properties

In addition to being colloidally soluble, or dispersible in water, gums are insoluble in drying oils and organic solvents. On heating they decompose completely without melting, usually showing charing. In contradistinction, natural resins are insoluble in water, but more or less soluble in organic solvents and vegetable oils. When heated, resins melt with distillation of volatile oils as the temperature is increased. They do not show a carbonizing point, nor do they produce coke when destructively distilled. Gums are totally unrelated to resins—physically, chemically or application-wise.

True gums are roughly divisible into three classes: *a*) truly soluble gums, typified by gum arabic, which form transparent colloidal solutions in water; *b*) so-called insoluble gums, represented by tragacanth, which absorb the aqueous medium, swell into a jelly and finally, on addition of sufficient water, break down into a very thick transparent solution; *c*) half-soluble gums, represented by so-called "Persian insoluble gum", which are intermediate in their properties, dispersing in water to form a swollen jelly and then passing into solution on addition of more water.

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[1] This article is abstracted, with permission of the copyright owners, from the book "The Water-Soluble Gums", 279 pages, by the same author and published in 1947 by Reinhold Publishing Corp. That volume contains much chemical and technological information concerning gums which has been omitted from this condensed version of the book.

In addition to these differences in solubility, the various gums differ from one another in a number of other physical qualities, and these differences render them suitable for different industrial uses, as explained later. Each of the gums finds specific application in industrial usage where the others neither replace nor supplement it; each has earned its place over thousands of years or in a short span of time after it reached a stage of commercial production.

Chemical Properties

Gums, in general, are complex associations of celluloses, starches, sugars, the reaction and oxidation products of these materials and the acids and salts of compounds consisting only of carbon, hydrogen and oxygen. They are thus closely related chemically to the carbohydrates. In addition to the three mentioned elements, they contain more or less mineral matter, chiefly calcium, magnesium and potassium. Nitrogen is in many cases a component but not always. In this respect gums differ from proteins, of which nitrogen is an essential component.

On hydrolysis gums yield various products which betray their chemical makeup, as shown in Table 1.

Commercial Sources

Commercial gums are obtained by tapping, or by collecting them from the surface of, certain trees and shrubs; by extraction from marine plant life; by milling from some seeds and extraction from others; by thermal treatment of starches from kernels or root crops; by chemical processing of cellulose from tree trunks and the cotton plant; as well as by separation of animal by-products and purification procedures.

The water-soluble gums enter commerce from many portions of the world, mostly from agricultural and non-industrialized areas. In general, they originate in the following parts of the African continent: the Sudan (Sudan or Kordofan gum); the forest of the Blue Nile (talh or talha gum); the French Colony of Senegal (Senegal gum); Northern Nigeria (gum arabic); Morocco ("Morocco", "Mogadore", "Brown Barbary" gum); Tripoli (gum arabic); Tunisia (gum arabic); Tanganyika (gum arabic); Southwest Africa (acacia); Cape Colony, Orange River Colony, Somaliland and Abyssinia (Aden and East Indian gum); in portions of Asia, as India and adjacent countries (ghatti and karaya gum); in Asia Minor, Kurdistan and Iran (tragacanth); in Australia (wattle gum); in South America where usage is mostly local; and to a small extent in Europe (cherry gum).

The seaweed colloids—agar, Irish moss and the alginates—are derived from marine products gathered off the coast of Japan, the east and west coasts of the United States, the marine areas of the British Isles and Europe, and the shores of the Atlantic and Pacific Oceans.

The processed carbohydrates, *e.g.*, dextrins and British gums, are derived from American starches such as corn and potato, as well as tapioca from the Netherlands Indies. The hemicelluloses are from seeds of trees and other plants from Europe, Iran, the Argentine and the United States. Gelatin is ordinarily derived from animal sources in the United States. Synthetic competitors of the gums, such as the processed celluloses, are from native or Canadian wood pulp or American cotton linters.

Gum Arabic

The dried gummy exudations from the trunks and branches of many species of *Acacia* have been collected since Biblical times and constitute the true gum arabic of commerce. The term has been applied also in a very broad general sense to almost any gum, regardless of its botanical source, which disperses in water to form a mucilage. True arabic, however, is yielded only by species of *Acacia*. Some 400 of them are widely distributed over very extensive areas of arid northern Africa, from Dakar and Senegal on the west Coast across the continent to the Red Sea; throughout Arabia; and in portions of Iran, India and Australia. They are found also in the semi-arid areas of the American Southwest, in Mexico and in Central America. Other sections of the tropics throughout the world also have their representatives of the genus. Only a few of these many species, however, are commercially important.

The term "gum arabic" has become generic, although it was originally a locality designation. As such it has been superseded by other names indicating areas in which the exudations are collected. These are "Sudan gum", "Kordofan gum", "Khartoum gum", "Turkey gum", "Senaar gum", "Geddaref gum", "Jeddah gum" and others. Although not so broadly used and often employed only locally, there are also "Gedda gum", "Sennari gum", "Turic gum" and "Gehzirah gum". In general the different varieties of exudations from acacia trees are collected in the Sudan of Africa, Upper Egypt, Ethiopia, Somaliland and adjacent areas. The most important of them are grouped under two general categories, namely, "Sudan" or "Kordofan", and "Senegal".

TABLE 1.

COMPOSITION AND HYDROLYSIS PRODUCTS OF NATURAL GUMS

Gum	*Apparent Chemical Composition*	*Hydrolysis Products*
Agar	Sulfuric ester of a linear galactan	......
Algin	Polyuronic acid	Cellulose, uronic acid, mannuronic acid
Arabic	Metal salt of a complex organic acid	Mixture of arabinose, galactose, aldobionic acid, galacturonic acid
British gum	Modified carbohydrate	......
Dextrin	Modified carbohydrate	......
Flaxseed	Heterogeneous polysaccharide	Aldobionic acid, *d*-galacturonic acid, *l*-rhamnose
Ghatti	Calcium salt of polysaccharide acid	*l*-arabinose, barium salt of aldobionic acid
Guar	Complex carbohydrate, galactose, mannose	......
Iceland moss	Cellulose, simple sugars	*d*-glucuronic acid
Irish moss	Calcium salt of sulfuric ester of saccharide	Ethereal sulfates (glucose)
Karaya	Galactan, gelose	......
Locust bean	Carbohydrate, mannose, galactose	Caronbinose (mannose), galactose
Methyl cellulose	Synthetic cellulose ether	......
Psyllium seed	Mixture of polyuronides	Arabinose, *d*-glucose, *d*-xylose, aldobionic acid
Quince seed	Cellulose, arabinose, xylose	Arabinose, mixture of aldobionic acids, cellulose
Tragacanth	Calcium salt of complex organic nature	Glucuronic acid, arabinose

Designations

Gums are known by a great variety of names in different parts of the world. These designations are tabulated in Table 2 wherein the local name or trade variant is in the first column, the geographical place of origin in the second column, the botanical source in the third, and the present day classification, as used in this paper, in the last column.

TABLE 2.

DESIGNATIONS AND SOURCES (GEOGRAPHICAL AND BOTANICAL) OF COMMERCIAL GUMS

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
A			
Abyssinia	Abyssinia	*Acacia*	Arabic
Acacia	Africa, Near East	*Acacia*	Arabic
Aden	Africa	*Acacia*	Arabic
Agar	Continental and Japanese Sea Coasts	*Gelidium*, *Gracilaria*	Agar
Aleppo	Near East	*Astragalus*	Tragacanth
Algin	British Isles, Europe, United States, Nova Scotia	*Laminaria*, *Macrocystis*	Alginate
Angelique	South America	*Dicorynia*	Karaya substitute
Angico	South America	*Piptadenia*	Arabic substitute
Anogeissus	India	*Anogeissus*	Ghatti
Arabic	Africa, Near East	*Acacia*	Arabic
Arrehbor	Iran (Persia)	*Astragalus*	Tragacanth
Astragalus	Iran, Asia Minor, Armenia, Kurdistan, Palestine, Irak, British India, Russia, Turkey	*Astragalus*	Tragacanth
Australian black wattle gum	Australia	*Acacia*	Arabic
B			
Babool	India	*Acacia*	Arabic
Balsam (resin)	Canada, United States	*Abies*	Canadian balsam
Barbary, brown	Sudan, Africa	*Acacia*	Arabic
Bar Kanten	Japan	*Gelidium*	Agar
Basra	Iran (Persia), Near East	*Astragalus*	Tragacanth
Bassora	Iran (Persia)	*Sterculia*	Karaya
Beira	Argentina	*Caesalpinia*	Karaya substitute
Berbera	Senegal, Africa	*Acacia*	Arabic
Blanche gomme	Sudan, Africa	*Acacia*	Arabic
Blonde gomme	Sudan, Africa	*Acacia*	Arabic
Blonde psyllium seeds	Mediterranean area	*Plantago*	Psyllium
Brea	Argentina	*Caesalpinia*	Karaya substitute
Broadleaf kelp	Europe, United States	*Laminaria*	Alginate
Bushire	Iran (Persia)	*Astragalus*	Tragacanth
C			
Cactus	United States, Mexico, Central and South America	*Opuntia*, *Carnegeia*	Tragacanth substitute
Canada balsam (resin)	Canada, United States	*Abies*	Canadian balsam
Cape	Union of South Africa	*Acacia*	Arabic
Carmania	Syria	*Prunus*	Ghatti substitute
Carob	South Europe, North Africa, Mediterranean area	*Ceratonia*	Locust bean
Carob seed	South Europe, North Africa, Mediterranean area	*Ceratonia*	Locust bean
Carrageen	British Isles, New England, Europe, Nova Scotia	*Chondrus*	Irish moss
Carragheen	British Isles, New England, Europe, Nova Scotia	*Chondrus*	Irish moss

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
Carrageenin	British Isles, New England, Europe, Nova Scotia	*Chondrus*	Irish moss
Cashew	India	*Anacardium*	Arabic substitute
Catechu	India	*Acacia*	Arabic
Cedar	Central America, West Indies	*Cedrela*	Cedar
Cedro	Central America, West Indies	*Cedrela*	Cedar
Cherry	Europe, United States	*Prunus*	Cherry
Chinese isinglass	Japan, China	*Gelidium*	Agar
Chironji	India	*Buchanania*	Karaya
Chitira	Persia	*Astragalus*	Tragacanth
Chittagong	India	Indefinite	Indian
Chondrus	British Isles, North Europe, New England, Nova Scotia	*Chondrus*	Irish moss
Cutch gum	India	*Acacia*	Arabic
Cydonium	Near East, Asia, Europe, South Africa, United States	*Cydonia*	Quince seed
D			
Date gum	Africa	*Phoenix*	Date
Dhak	India	Indefinite	Indian
E			
East India gum	India, (East Indies)	*Acacia*	Arabic
East Indian gum	Iran (Persia)	*Acacia*	Arabic
Elephant	India	Indefinite	Indian
F			
Flea seed	Mediterranean area	*Plantago*	Psyllium
Fleawort	Mediterranean area	*Plantago*	Psyllium
G			
Gatto	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Gavan	Iran (Persia)	*Astragalus*	Tragacanth
Gedda	Africa	*Acacia*	Arabic
Geddaref	Egypt	*Acacia*	Arabic
Gehzirah	Africa	*Acacia*	Arabic
Ghati	India, Ceylon	*Anogeissus*	Ghatti
Ghatti	India, Ceylon	*Anogeissus*	Ghatti
Goma de Cedro	Central America, West Indies	*Cedrela*	Cedar gum
Goma de Guanacaste	Central America, West Indies	*Enterolobium*	Arabic substitute
Gomme blanche	Sudan, Africa	*Acacia*	Arabic
Gomme blonde	Sudan, Africa	*Acacia*	Arabic
Gomme de Galam	Senegal, Africa	*Acacia*	Arabic
Gomme de Podor	Senegal, Africa	*Acacia*	Arabic
Gomme de Tombouctou	Senegal, Africa	*Acacia*	Arabic
Gomme du bas du fleuve	Senegal, Africa	*Acacia*	Arabic
Gomme du haut de fleuve	Senegal, Africa	*Acacia*	Arabic
Gomme fabrique	Senegal, Africa	*Acacia*	Arabic
Gomme friable	Senegal, Africa	*Acacia*	Arabic
Guamacho	South America	Cactus	Tragacanth substitute
Guar	India, United States	*Cyamopsis*	Guar
H			
Halusia	Iran (Persia)	*Astragalus*	Tragacanth
Hashab geneina	Egypt	*Acacia*	Arabic
Hashab wady	Africa	*Acacia*	Arabic
Hevo	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Hindu tragacanth	India	*Sterculia*	Karaya
Horsetail kelp	Europe, United States	*Laminaria*	Alginate

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
I			
Iceland moss	Iceland, Sweden, Norway	*Cetraria*	Iceland moss
India gum	India	*Sterculia*	Karaya
Indian gum	India, Ceylon	*Anogeissus*	Ghatti
Indian tragacanth	India	*Sterculia*	Karaya
Irish moss	British Isles, Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Isabghol	Mediterranean area	*Plantago*	Psyllium
Isinglass	Continental sea coasts	*Gelidium, Gracilaria*	Agar
J			
Jandagum	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Japanese gelatin	Japan	Seaweed	Agar
Japanese isinglass	Japan	*Gelidium, Gracilaria*	Agar
Jeddah	Morocco	*Acacia*	Arabic
K			
Kadaya	India	*Sterculia*	Karaya
Kanten	Continental sea coasts	*Gelidium, Gracilaria*	Agar
Karai	Iran (Persia)	*Astragalus*	Tragacanth
Karaya	India	*Sterculia*	Karaya
Katad	Iran (Persia)	*Astragalus*	Tragacanth
Kathira	Iran (Persia)	*Astragalus*	Tragacanth
Katilo	India	*Sterculia*	Karaya
Katira	Iran (Persia)	*Astragalus*	Tragacanth
Katira-i-hindi	Iran (Persia)	*Sterculia*	Karaya
Katya	Iran (Persia)	*Astragalus*	Tragacanth
Katyra	Iran (Persia)	*Astragalus*	Tragacanth
Keltex	United States	*Laminaria*	Alginate
Kettira	Iran (Persia)	*Astragalus*	Tragacanth
Khartoum	Africa	*Acacia*	Arabic
Killeen	British Isles, Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Kino	India	*Pterocarpus*	Indian gum
Kobe	Japan	*Gelidium*	Agar
Kordofan	Sudan, Africa	*Acacia*	Arabic
Kullo	India	*Sterculia*	Karaya
Kuteera	Asia, Iran (Persia), India	*Sterculia*	Karaya
Kutera	Iran (Persia)	*Astragalus*	Tragacanth
L			
Lakoe	Africa, South Europe, Mediternean area	*Ceratonia*	Locust bean
Locust bean	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Locust kernel	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust kernel
Lupogum	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Luposol	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
M			
Mahua	India	*Bassia*	Indian gum
Mangrove	North and South America	*Rhizophora*	Ghatti substitute
"Marrons et bois"	Africa	*Acacia*	Arabic
Mesquite	United States, Mexico, South America	*Prosopis*	Arabic substitute
Mimosa	West Indies, South America	*Mimosa*	Tragacanth substitute

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
Mogador	Africa	*Acacia*	Arabic
Moringa	India	*Moringa*	Karaya substitute
Morocco	Africa	*Acacia*	Arabic
O			
Ondurman	Egypt	*Acacia*	Arabic
P			
Peach	United States	*Prunus*	Peach gum
Pearl moss	Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Persian tragacanth	Iran (Persia)	*Astragalus*	Tragacanth
Pharmagel	United States	Protein	Gelatin
Pigwrack	Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Plantago	Mediterranean area	*Plantago*	Psyllium
Plum tree gum	India	*Prunus*	East Indian gum
R			
Ritha	East Indies	*Sapindus*	Ghatti substitute
Rocksalt moss	Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Rubigum	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
S			
Seaweed isinglass	Japan	*Gelidium*	Agar
Saghalien	Japan	*Gelidium*	Agar
Salabreida	Senegal, Africa	*Acacia*	Arabic
Semla	India	*Sterculia*	Karaya
Senaar	Central America	*Acacia*	Arabic
Senegal	Africa	*Acacia*	Arabic
Sennaar	Africa	*Acacia*	Arabic
Shinshu	Japan	*Gelidium*	Agar
Shiraz	Iran (Persia)	*Anogeissus*	Ghatti
Smyrna tragacanth	Kurdistan, Iran (Persia), Irak	*Astragalus*	Tragacanth
Siris	India	*Albizzia*	Arabic substitute
Soap-nut tree gum	East Indies	*Sapindus*	Ghatti substitute
Sonora	United States, North and South America	*Prosopis*	Arabic substitute
Sterculia	India	*Sterculia*	Karaya
St. John's bread	Africa, Mediterranean area, Europe	*Ceratonia*	Locust bean
Suakim	Africa	*Acacia*	Arabic
Sudan	Africa	*Acacia*	Arabic
Suleimanaya	Iran (Persia), Irak	*Astragalus*	Tragacanth
Somaliland	Somaliland	*Acacia*	Arabic
Sunt	Arabia, Africa	*Acacia*	Arabic
Swine's bread	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Syrian	Syria	*Astragalus*	Tragacanth
Syrian tragacanth	Kurdistan, Iran (Persia), Irak	*Astragalus*	Tragacanth
T			
Talba	Sudan, Africa	*Acacia*	Arabic
Talca	Sudan, Africa	*Acacia*	Arabic
Talh	Africa	*Acacia*	Arabic
Talha	Africa	*Acacia*	Arabic
Tengusa	Japan	*Gelidium*	Agar
Terminalia	India	Indefinite	Indian
Thus gum (resin)	United States	*Pinus*	Rosin
Tragacanth	Iran (Persia), Turkey, Russia, Irak, Palestine, British India, Syria	*Astragalus*	Tragacanth

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
Tragon	Africa, Mediterranean area, South Europe	*Ceratonia*	Locust bean
Tragasol	Africa, Mediterranean area, South Europe	*Ceratonia*	Locust bean
Tripoli	Africa	*Acacia*	Arabic
Tunis	Africa	*Acacia*	Arabic
Turic	Africa	*Acacia*	Arabic
Turkey gum	Near East	*Acacia*	Arabic
V			
Vegetable isinglass	Japan	*Gelidium*	Agar
W			
Wattle	India, Australia, Africa, New South Wales	*Acacia*	Arabic
White gum (gomme blanche)	Africa	*Acacia*	Arabic
White leaf gum	Kurdistan, Iran (Persia), Irak	*Astragalus*	Tragacanth
Y			
Yokohama	Japan	*Gelidium*	Agar

Sudan or Kordofan Gum. In the Anglo-Egyptian Sudan and French Senegal areas of Africa alone there are about 25 species of *Acacia,* and of these, *A. Senegal* (L.) Willd., a tree of small size, is by far the most important. There are extensive forests of it in the region of Kordofan which is west of Khartoum in the Anglo-Egyptian Sudan, and it is abundant also between the White Nile and the Blue Nile. In the Sudan Area the tree is often called "hashab", which term the Egyptians and Arabs apply also to the gum.

Commercial production of the gum in this semi-arid country is limited necessarily to those districts which are not too far from sources of water. The gum gatherers must carry all their provisions of food and water, and this limits their collecting to areas which are only a few days journey from depots for replenishment of these supplies. The gum is gathered only in the hottest and driest season because in other seasons the trees are actively growing with sufficient moisture and do not produce gum. The best yields result when an unusually hot dry season follows one of excessive rainfall.

Gum collecting is not an all year vocation for the natives but rather a source of additional income when farming is at a standstill. Although the dry season normally begins in the latter part of September or in October, and the trees may be tapped any time after the first of November, gum gathering is postponed until after the crops have been harvested. The gatherers, therefore, are active only after January or February. The men leave their native villages, carrying their food and water supply, with a spear for defense against native animals or as a hunting implement. Their only gum-gathering tool is a small hatchet with a long handle, and a native woven basket to serve as a container of the collected gum. The collectors cut the trees in not too deep a fashion and then peel a strip of bark an inch or two in width and two to three feet long. Care is taken not to injure the inner bark. The stripping operation is not sufficient to harm the tree, and in time under favorable conditions the wound heals. It appears that the gum is formed through a combination of evaporation of the sap and attack on the plant tissues by bacteria. The gum exudes and forms in drops, or tears, which grow to large size

FIG. 1. Exudation of gum arabic at a point of tapping. Kordofan, Sudan, Africa. (*Courtesy the Philadelphia Commercial Museum*).

only after a season of heavy rains which induce the trees to become full of sap and to develop vigorous young growth. When first formed, the tears are soft, the outside being skin-like; but if they are allowed to remain in place for several weeks, the entire mass becomes firm and hard as a result of evaporation from the surface and diffusion of aqueous portions from within the tear to its outside. which are transparent or nearly so, with only a faint departure from white.

The gum is spread in the sun in thin layers to bleach. The best area for this purpose, according to the natives, is the low sandy shore of the Nile. The drying out in the sun is at a faster rate than the moisture can diffuse from the inside of the tears, so that with expansion and contraction after drying, the tears are filled with innumerable minute cracks. These cause the gum to assume an opaque appearance and a greater degree of whiteness, characters that are typical of good commercial grades. It is unfortunate, however, that these features do not give any indication of the factors to be considered in the use of the gum, namely, color of solution, viscosity, clarity and freedom from insolubles. Cheaper grades are yellowish to red.

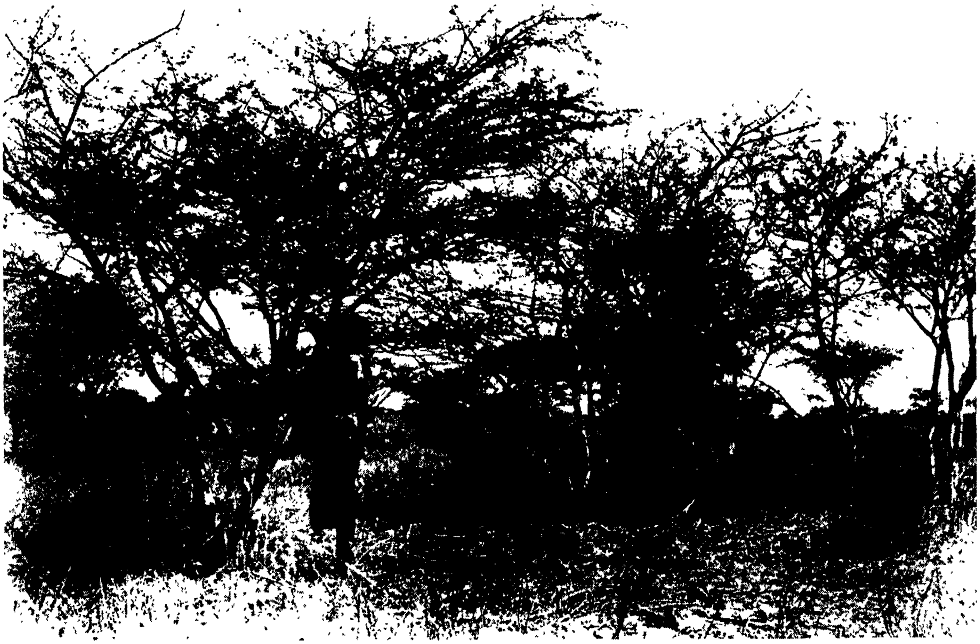

FIG. 2. Gum-arabic garden near Tairara, Kordofan, Sudan, Africa. (*Courtesy the Philadelphia Commercial Museum*).

The gum collectors return with their produce to the villages and sell or barter their gatherings to local traders or representatives of district gatherers. When sufficient stocks are collected, the gum is transported by boat or caravan to wholesale markets, of which Khartoum is typical. Here the gum is graded on the basis of superficial appearance, and in the light of centuries of experience the best grade is reputed to be that of tears

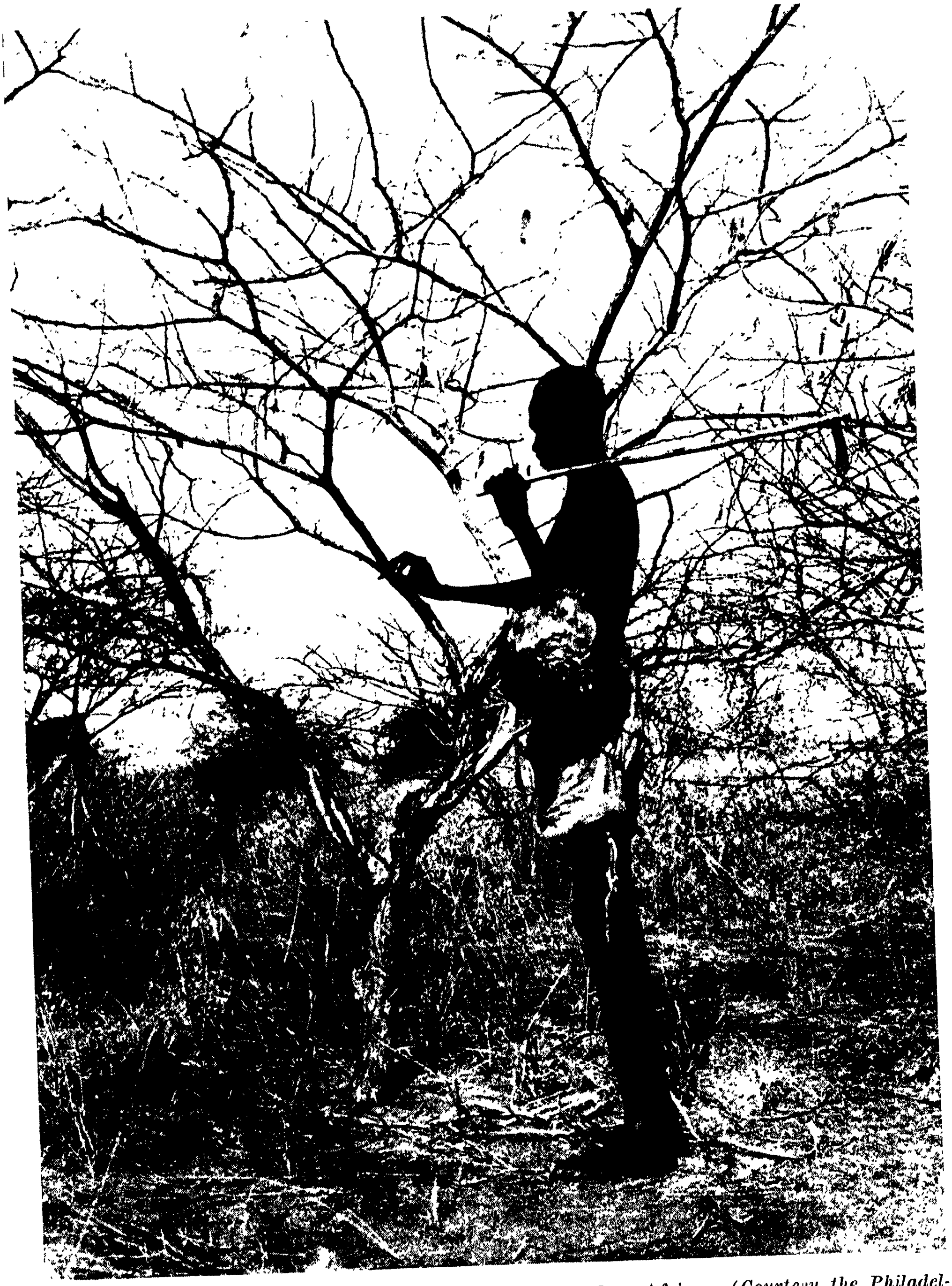

FIG. 3. A native gum-arabic collector. Kordofan, Sudan, Africa. (*Courtesy the Philadelphia Commercial Museum*).

Gum arabic in the restricted geographical sense is the material exported chiefly to Europe from Arabia, most of the trade being handled in the port of Aden. Only a very small portion of the gum, however, is collected in Arabia. For two or three thousand years natives have gathered the gum from wild trees in those parts of Africa adjacent or accessible to the southern end of the Red Sea. The more important traders who collected from the natives were along the Arabian coast, and the gum received its name from them, for it was these arabs who exported the material to Europe. There are indications that caravans carried the gum to North Egypt from Aden as early as the seventeenth century before Christ. The bulk of the material in earlier times was collected, as it is today, in the Sudan, and has long been known as "Sudan" or "Kordofan" gum.

In addition to the wild tree scattered over great areas there are also privately owned cultivated gardens of *A. Senegal* in Kordofan Province. Here the trees are systematically tapped and the gum collected in an orderly manner by organized groups. The gum thus produced is known as "hashab geneina" and is considered the best grade; it is referred to also as "gum acacia" and is the grade preferred in the American market. The gum collected from wild forests is known as "hashab wady", and because of the multiplicity of collectors whose work is necessarily uncoordinated, wady gum is generally of poorer grade and darker color.

Gum Senegal is obtained from *A. Senegal* and other but poorly defined species in West Africa. The trees cover great areas west and southwest of the Sahara and the French Sudan, extending through Senegal, Gambia, French Sudan, Ivory Coast, northern Dahomey and Nigeria. It is known also as "Berbera gum", "gomme de Galam", "gomme de Podor", "gomme de Tombouctou" and by a variety of other local names.

A large portion of the material reaching the market is from the country north of the Senegal River, a region which is easiest for the natives to penetrate and which is close enough to the coasts and the routes of the traders. In the region of the greatest gum collections abundant rains occur from July to November. The rainfall is so heavy that large areas become temporary swamp land. During these periods the trees grow luxuriously and become filled with sap with abundant new growth. The rainy season ends abruptly, being followed by a period of hot, dry, scorching, high velocity east winds. The rapid change in weather cracks the outer bark into many open fissures which become foci of infection for gum formation, and within a few weeks after the onset of the dry season there is a considerable accumulation of exudation.

The French system of sorting gum Senegal includes a considerable variety of grades. In general, the gum is yellower or redder than the relatively pale gum from the eastern Sudan. It is reputed to be not so clean as the Kordofan grades and is less favored by American importers and their customers. Furthermore, unless they are first subjected to mechanical and chemical processing, the Senegal grades are thought not to be so adhesive as those from Kordofan. They do, however, form solutions of greater viscosity and find a large European market.

Other Kinds of Gum Arabic. There appears to be general agreement that small amounts of gum are gathered in the Sudan and adjacent territories from *A. arabica* (Lam.) Willd. It is probable that gum from this tree, particularly that gathered from the forest areas, is unconsciously mixed with the gum from other species of *Acacia*. When not so mixed but gathered by itself it is often sold under the name "sunt". It is stated to be inferior to Sudan gum, being considerably weaker and more brittle, and reaches the market as broken white or pale yellowish fragments. In the American market sunt does not appear to be important except as it occurs in admixtures.

Several species, and probably varieties, of *Acacia* furnish a form of gum arabic known as "suakim gum". It is from the regions adjacent to the western shores of the Red Sea, although some of the material may be brought by caravans from distant points. As a result of its relatively unsupervised collection it is ordinarily of inferior quality, although the quantities are important.

A. Seyal Del., widely distributed in the Sudan, is the source of a gum known as "talh", "talca" and "talba". It occurs in two forms, red and white.

Some gum is gathered from several species of *Acacia* in North Africa, but it is probable that considerable of the material that reaches there has been brought by caravans from south of the desert. It is known that some of these gums are gathered, not by organized caravans but by what might be termed "tramp" traders who transport gums as portions of miscellaneous cargoes. According to their points of entrance into commerce they are variously known as "Barbary gum", "Morocco gum" and "Mogador gum".

All these secondary gums and those of Sudan and Senegal are alike chemically and are regarded as gum arabics of different purities, varying also in degree of color, adhesiveness and viscosity.

Other Gums from Acacia

Several kinds of *Acacia* in India, probably both native and introduced species, also yield gums of economic value, though not at all so important industrially as gum arabic. They are included in that general term "East Indian gum" and must be distinguished from resins of India which are designated as "Pale East India", "hiroe" or "rasak". There appears to be random collection and transportation of these materials, and a large percentage comes to Bombay from Red Sea ports on the African coast. Some of it, however, is collected in various parts of India and finds its way to the trading and exporting centers. A particularly specific Indian gum is that designated as "babool", but in general the East Indian gums, because of their random collection and sorting, are of inferior quality and are often mixed with more important gums such as ghatti. *A. Catechu* (L.) Willd., which yields catechu extract, or cutch, an important brown dye, also produces a yellow-to-dark amber gum that is much used in India in textile applications as a substitute for gum arabic. Some of it reaches the commercial markets, but largely as an admixture in East Indian gum.

In Australia various native species of *Acacia* supply so-called wattle gum, production of which is secondary to utilization of the trees for wattle bark employed by tanners in the conversion of hides into leather. The gum is dark reddish and otherwise distinct from gum arabic in having a strongly astringent taste and an analyzable quantity of tannin derived from the bark.

Cape gum, gathered from acacia trees in Cape Colony, Union of South Africa, is somewhat similar to Australian wattle gum, and at times in the past has entered commerce in appreciable quantities.

In the western hemisphere samples of acacia gum from the southwestern United States or Mexico periodically appear on the market, and other samples occasionally are collected in Central and South America, particularly from *A. Farnesiana* Willd.

Gum Tragacanth

Gum tragacanth is perhaps the second most important commercial water-soluble gum, being surpassed only by gum arabic and rivaled only by gum karaya. It is furnished by several species of *Astragalus,* thorny leguminous shrubs native to semi-desert regions of western Asia and southeastern Europe, but principally by *A. gummifer* Lab. which grows wild in the mountainous districts of Kurdistan, Iran, Iraq, Syria, Asia Minor, Armenia, Greece and Russia. In Iran the natives refer to the plants as ''gavan'', and to the gum as ''katira'', ''katyra'', ''kathira'', ''katad'', kettira'', ''kutera'', ''chitera'' and ''halusia''. These names are used also in Afghanistan and India, and in the latter other gums are sometimes sold as ''katira'', ''karai'' and ''katira-i-hindi'' or ''Hindu tragacanth''. It appears that the gum is not a true secretion of the shrubs that produce it, but is the result of transformation of pith and medullary ray cells into a mucilaginous substance that exudes naturally or after the bark has been punctured or excised. It swells in cold water, forming a thick and ordinarily transparent jelly, and is less brittle, less glassy and duller in luster than arabic.

While the gum exudes spontaneously to the surface of the bark, it is obtained in commercial quantities by making punctures or transverse incisions in the main stems and older branches of the shrubs. Wedge-shaped pieces of wood are frequently forced into the incisions in order to enlarge the wounds so that the gum will flow more freely, and are left in the cuts a day or two before being removed. The gum swells by absorbing water, and the resultant pressure set up within the stem, rather than any biological force, causes the gum to exude. It is allowed to dry on the bark a few days before being collected and shipped to market. Collection is in May and June in the warmer districts; later in cooler areas where the best grades are obtained. Sometimes the plants are partly burned to stimulate excretion, but the product is inferior and the practice not general.

After collection and shipment to various markets, the miscellaneous pieces of gum are sorted into the following three general classes within which are the various commercial grades—common tragacanth, or ''tragacanth in sorts'': rounded or irregularly shaped tears or globules, representing gum that has exuded through naturally produced ruptures in the bark; vermicelli, or vermiform tragacanth: elongated, narrow, twisted strings or coils originating from stems which have been cut entirely across or from gum forced through rounded holes; flake tragacanth, also called ''Persian'', ''Syrian'' and ''Leaf'' gum: ribbon-like nearly colorless pieces exuding from slits made in the main stem near the root after clearing away the soil to a depth of about two inches; this is considered the highest grade on the market. Powder and aqueous solutions are also offered to the trade, the latter for certain specialized uses and generally treated to endow it with desired specific properties.

''Persian'' tragacanth usually embraces the better grades from a number of areas. ''Bagdad'' and ''Syrian'' refer chiefly to gum which passes through Bagdad and is shipped through Basra. ''Bushire'', or ''Persian'', consists mainly of the gum from the Province of Fars in Iran and is shipped from Bushire. Turkish gum comes chiefly from Istanbul, other small lots occasionally are shipped from Bombay and Aleppo, and in Smyrna there is an important wholesale market where the gum is sorted before being sent to European distributing centers in Trieste, Bordeaux, London and Hamburg.

The annual United States consumption of gum tragacanth from 1929 to 1940 averaged about 2¼ million pounds, being imported chiefly from Iran and Turkey, with imports also from Russia, Iraq, British India, Syria and Palestine. Prior to World War I Turkey was the most important source, but for many years since then Iran has supplied the greatest amounts, and its products are superior.

Tragacanth is one of the oldest drugs in Materia Medica, and its commercial use dates far back. It was known in the days of Theophrastus who described it three centuries before the Christian era. It has been official in every edition of the U. S. Pharmacopoeia since 1820, being used medicinally as a demulcent and pharmaceutically as an adhesive agent for pills and troches and for the suspension of insoluble powders. Other industrial uses are discussed later.

Indian Gums

Gums of various natures and obtained from different genera of plants are collected in parts of India. They constitute an important portion of the world's total production of gums and a large part of the American consumption. In most cases they are the exudations of large trees, whereas the gums of the arabic and tragacanth groups are collected from small thorny trees which in some cases are bush-like. Only a few of the Indian gums have reached the stage of continuous commercial collection, grading and organized trading on a recognized quality basis. Of them the first two next described are the most important. The others have only local uses, for the most part.

Gum Ghatti. This one, known also as "Indian gum" and "Ghati gum", is obtained from the trunk of *Anogeissus latifolia* Wall., a large tree, widely distributed in India and Ceylon, the leaves of which are rich in tannin and used for tanning in Bombay. Uses of the gum are similar to those of arabic, for which it is employed in India and certain other parts of the British Empire as a substitute in official pharmaceutical preparations.

Ghatti gum should not be confused with either Bassora or gum Sterculia, next described, each of which is sometimes referred to as "Indian gum".

Gum Karaya. Gum Karaya has become an important raw material in the textile, cosmetic, food and other industries, resembling gum tragacanth in that it swells in cold water to form an opaque gel. It has been used in the United States since the latter part of the 19th century, but large scale use here dates from World War I when the price of tragacanth was high. Some of the gum sold as tragacanth, even before World War I, has undoubtedly really been karaya. Imports into the United States are far in excess of those of tragacanth, usually more than double; in 1939 they were in excess of 7,600,000 pounds with a declared value of $575,000 at the ports of export. In this country the gum is known also as "gum kadaya", "Indian tragacanth", "Sterculia gum" and "India gum", but is not to be confused with "Indian gum" which is one of the names of gum ghatti. In India it is called "karaya", "kadaya", "katilo" and "kullo".

Gum karaya is a product of *Sterculia urens* Roxb., a tree native to India and found chiefly in Gujerat, in the central provinces and to some extent in the Central Indian Agency. Attaining a height of 30 feet, the trees grow in forests which for the most part are government owned but some of which are on private estates. The gum is obtainable throughout the year except in the rainy season, and the best quality is collected during the hot spell from March through the middle of June. Usually five or six incisions about two feet long and deep enough to reach the heartwood are made in the tree trunks by natives. The gum oozes into the incisions and accumulates in large irregular knobs which are collected about every three days. New accumulations then form in the same incisions, but if the gum is not collected, the wounds heal and fresh incisions must be made elsewhere in the trees. Trees generally yield gum for eight or nine months, then cease for two or three years, after which they may again be tapped. The gum is collected by natives usually when there is scarcity of other work. It is taken to the villages where the merchants sell it to dealers in Bombay, and there sorting and grading are carried out, usually by women. Large lumps are broken with stones and sorted according to color and freedom from bark and other impurities. The best are white; the poorest dark brown to black.

Although the gum generally enters the United States as tears, nearly all that is sold to consumers is powdered, much of the bark being removed after powdering by an air blast. Colors vary from white to gray and often are reddish.

Other Indian Gums. Many other trees of India also produce gums which are collected, and when gathered in sufficient amounts they reach the export market. If the amounts are great enough, the individual gums may be sold under their own names; if the quantities are insufficient for such disposal, the gums from different kinds of trees may be lumped together to give irregular shipments of non-reproducible quality. The chemistry of these less important gums is little understood, and at times their botany and the identity of their sources is the subject of dispute. They are referred to by that broad term, "Indian" or "East Indian Gum", that

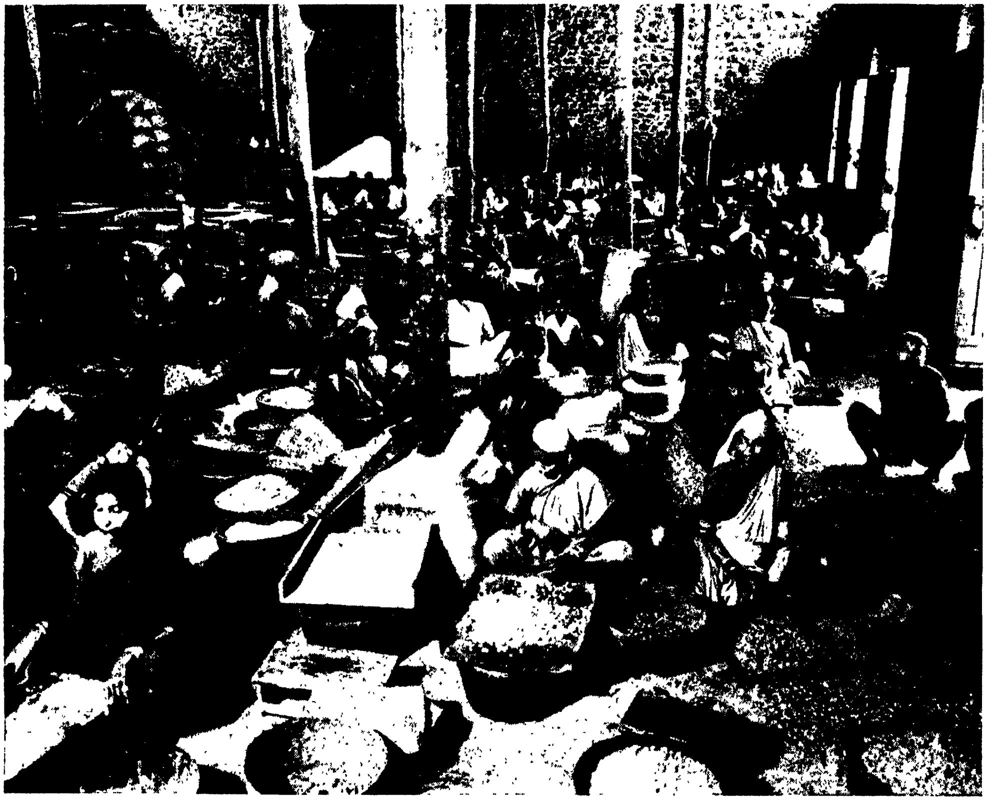

FIG. 4. Preliminary sorting of karaya gum. Bombay, India.. (*Courtesy the Philadelphia Commercial Museum*).

encompasses so many exudation products of Oriental trees. More specifically and in brief they are as follows:

Butea frondosa Roxb. Dhak or palas tree. Furnishes a red gum known as "Bengal" or "Palas kino", or "Butea gum".

Chickrassia tabularis A. Juss. Chittagong tree. Reddish to amber gum.

Terminalia spp. Several species furnish yellowish to reddish gums.

Acacia spp. These have been mentioned in connection with gum arabic.

Anacardium occidentale L. Cashew. Native to tropical America but cultivated in India and yielding a reddish gum.

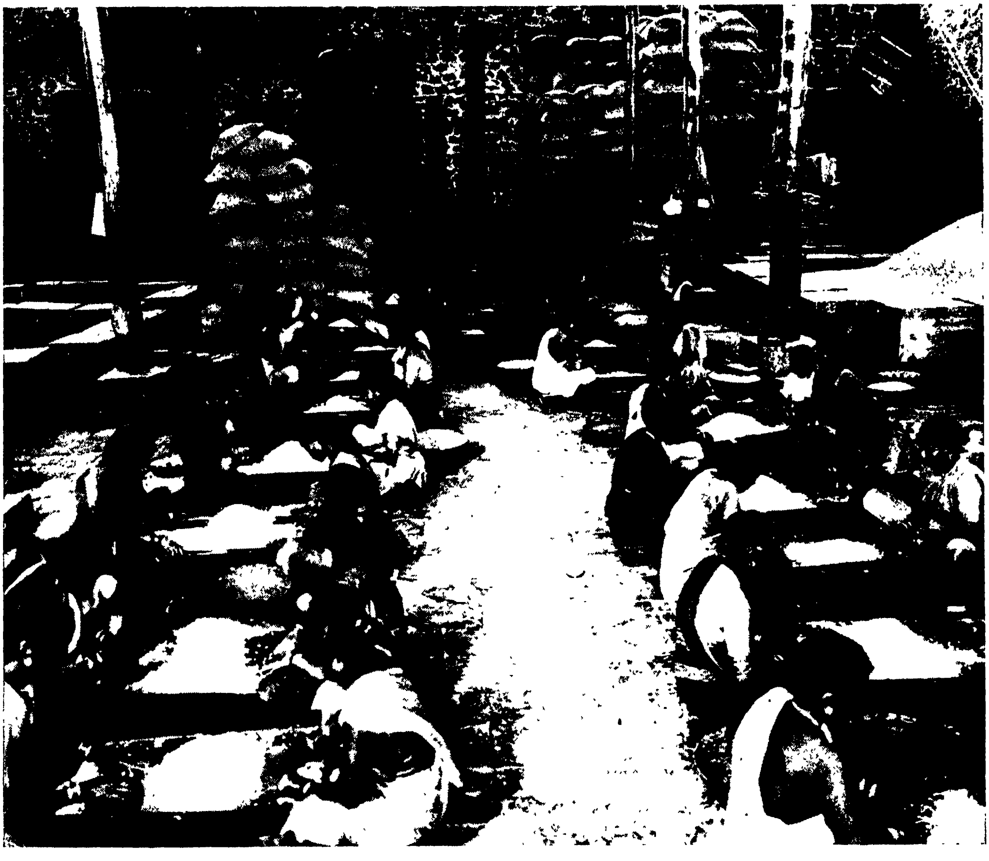

FIG. 5. Selecting and sorting karaya gum. Bombay, India. (*Courtesy the Philadelphia Commercial Museum*).

Pterocarpus Marsupium Roxb. Provides red kino gum. Commonly, however, "gum kino" is another name for dragon's blood which is a resinous substance obtained from the fruit of the climbing rattan palm *Daemonorops Draco* (Willd.) Bl. of eastern Asia and from the stem of *Dracaena cinnabari* Balf. of western Asia. Dragon's blood

Feronia elephantum Corr. Wood apple tree. Yellow to reddish gum.

Melia Azedarach L. China tree, Chinaberry tree, Pride of India. Gives an amber-colored gum.

Moringa pterygosperma Gaert. Horseradish tree. Ben. Furnishes moringa gum.

is not a gum but a gum-resin, and its commercial value for various purposes depends on its insolubility in water and its solubility in organic solvents.

Sapindus trifoliatus L. Yields soapnut tree gum, locally known as "ritha".

Cochlospermum Gossypium DC. Provides a very unimportant gum.

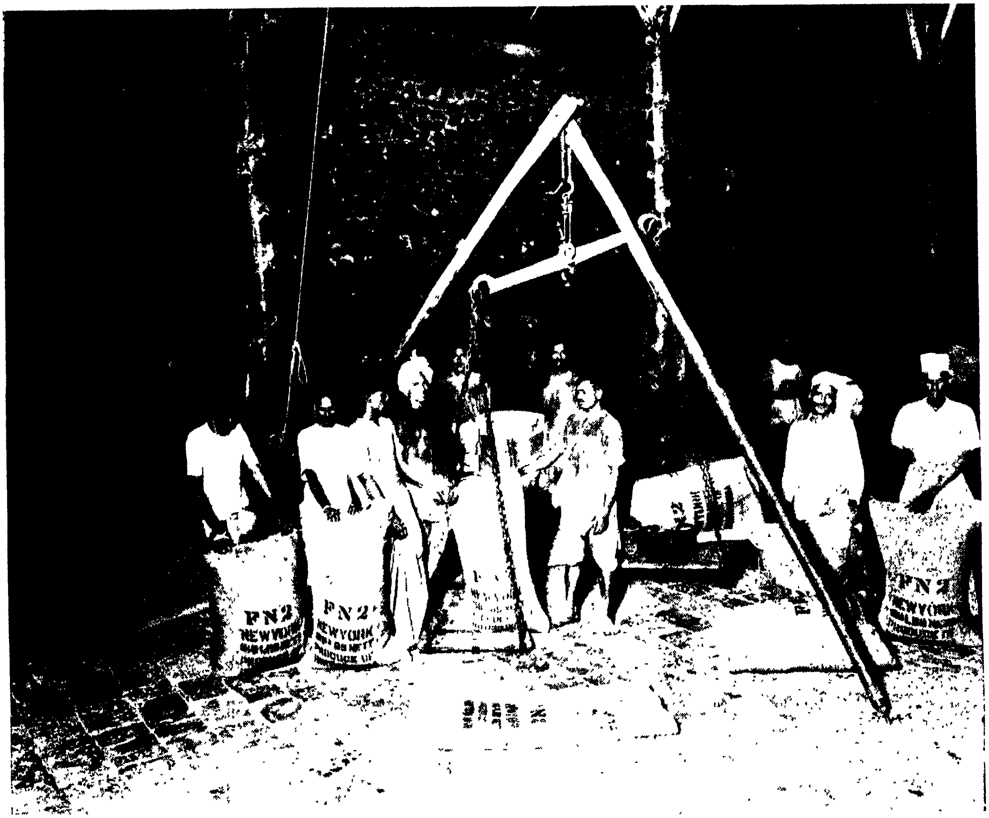

FIG. 6. Weighing and bagging karaya gum. Bomboy, India. (*Courtesy the Philadelphia Commercial Museum*).

Hemicelluloses

Hemicelluloses are organic compounds consisting of hydrogen, oxygen and carbon which are chemically related to, but somewhat different from, cellulose and other carbohydrates, occupying an intermediate position among them. They are contained in the seeds and fruits of many plants, and swell enormously when heated with water after extraction, serving, therefore, as thickeners in the same manner as gums do.

Vegetable ivory, or tagua, the hard seed of the Ecuadoran palm *Phytelephas macrocarpa* Ruiz & Pav., which is extensively used in making buttons, umbrella handles and other articles, owes its properties largely to the hemicelluloses of which it consists. Other hemicelluloses are gum-like and have commercial applications similar to those of the true gums. Since these uses are fairly specific, the hemicelluloses are industrially complementary to, rather than competitive with, the true gums, but their properties are such that they may fittingly be classed with them in any general discussion. The only ones which have commercial uses are the following.

Locust Bean Gum. This gum is obtained from the seeds of the carob, or locust bean tree, of Mediterranean countries, and its extraction involves the following successive stages: gathering the pods and spreading them out in the sun to dry; removing the ten or twelve red seeds in each pod by hand or machinery and packing them for shipment; removal of the outside skin and embryo by passage between rollers which turn in opposite directions, sometimes preceded by treatment with dilute caustic soda and subsequent washing; roasting; boiling in water; filtering and evaporating the cooled cooked liquor which contains the dispersed gum; pulverizing and packaging the dry brittle gum obtained by these operations. The degree of purification varies widely in the different lots shipped to the United States, since they are prepared in several countries and in a variety of manufacturing plants. The purer grades, referred to as "locust kernel gum", contain less starch and other impurities. Solutions of the gum, of about 4% concentration, and containing a preservative, such as formaldehyde or phenol, are also marketed.

The gum is imported into the United States from Great Britain and France, as well as from other parts of the Mediterranean region. Before 1926 only small amounts were used here, but in 1939 imports of the gum reached an all time high of more than 4,000,000 pounds; the average annual consumption from 1929 through 1938 was somewhat in excess of 2,000,000 pounds. American imports of beans and pods, amounting to 1,500,000 pounds in 1939, are primarily for tobacco curing, not for extraction of the gum, since transportation costs for that purpose would be prohibitive, inasmuch as 1,000 pounds of beans yield only 100 pounds of seed from which only 35 pounds of gum is obtainable.

Locust bean gum is known also as "carob gum", "carob seed gum", "St. John's bread", "swine's bread", "gum hevo", "gum gatto", "jandagum", "lakoe gum", "lupogum", luposol", "rubigum", "tragon" and tragasol". The evergreen leguminous tree that furnishes it, the carob (*Ceratonia Siliqua* L.), is a native of Syria and has been cultivated in many Mediterranean countries from antiquity for its large pods which are used somewhat as human food but principally as a very important farm crop for forage. Theophrastus, in the fourth century B.C., in his history of plants, mentions it as being cultivated at Rhodes, and Dioscorides, in the first century A.D., praises the fruit in his Materia Medica as a laxative and diuretic. The pods are rich in protein and sugar, and form an important forage crop, readily eaten by stock and by the poor in times of scarcity. The molasses and sirup made from them are used for flavoring tobacco before it is cured, and fermented to make a wine or a hard liquor.

Guar. Several years ago, as the result of investigations at the Institute of Paper Chemistry, Appleton, Wisconsin, supplies of locust bean gum were required for the purpose of confirming on a commercial scale a number of observations in the laboratory. Studies with paper had revealed that the gum is a valuable paper-maker's adjunct in obtaining temporary wet strength in sheets, such as paper toweling, and that this gum facilitates hydration during the beating of various pulps. A study of the matter revealed an inadequacy in the supply of locust gum, and an attempt was accordingly made to locate other sources of mannogalactans (locust gum consists primarily of mannose and galactose). The services of the Soil Conservation Commission of the U. S. Department of Agriculture were enlisted, and, as a result, numerous seeds were investigated for their potentialities. The most satisfactory of them were those of guar (*Cyamopsis tetragonolobus* Taub.), an annual drought-resistant legume, three to six feet tall, which has been cultivated in certain sections of India for centuries as fodder for cattle and horses. It was brought into the United States before World War I and has been studied on a limited scale, primarily as a green manure.

Guar gum resembles locust bean gum in being composed essentially of the complex carbohydrate polymer of galactose and mannose, but with different proportions of these two sugars. The practical value of this difference in the ratio of the two components is still the subject of study. Investigations carried out by the Institute of Paper Chemistry and numerous paper manufacturers have shown that guar flour is of value as a beater additive for improving the strength of certain grades of paper. It has been said that guar possesses properties which might be useful in warp sizing, printing pastes, and in certain finishing operations. The colloidal properties it possesses enable it to serve as a stabilizer or thickener in food products, such as ice cream and salad dressing.

In order to obtain the gum it is necessary to separate the gum-containing endosperm of the seed from the outer and largely fibrous portions. Milling methods have been developed for this purpose, and various grades of the gum can be isolated, ranging from products of high purity, to meet special requirements, to those of lower quality, designed for uses where high purity is not needed but where low cost of manufacture is important.

Flaxseed. The flax plant (*Linum usitatissimum* L.), extensively cultivated in many parts of the world for its fiber which is manufactured into linen, and for the linseed oil extracted from its seed for the paint and other industries, is also the source of a gum obtained in small quantities from the seed. This hemicellulose gum is of commercial value in the cosmetic and pharmaceutical industries because it acts as a demulcent and emollient.

Psyllium. Psyllium seed, which is extensively used as a mild laxative, is the source also of a mucilaginous gum that is readily extracted with boiling water. The gum serves in some instances as a substitute for gum arabic and tragacanth, and is utilized in the sizing of silk, printing of fabrics and manufacture of paper. It is obtained from at least three species of *Plantago*, namely, *P. Psyllium* L., *P. arenaria* Wald. & Kit. and *P. ovata* Forsk., the first mentioned being the most important. The first two are cultivated in France and Spain, the third in India, and in 1935 more than two million pounds of the seed were imported into the United States to be used principally as a drug.

Quince. Quince gum, also obtainable by boiling the seeds, has found value in the cosmetic industry as a demulcent in hand lotions, hair waving and cleansing lotions, and in medicinal preparations. The principal source is the quince (*Cydonia oblonga* Mill.) crop of Iran, smaller amounts coming from Iraq, Portugal and the Union of South Africa. Total imports of the seeds dropped from less than 222,000 pounds in 1941 to a little more than 154,000 pounds in 1942. In 1939, 63,869 bushels of the seeds were accumulated from the crop in the United States, principally in New York, Michigan, Pennsylvania and Maryland.

Iceland Moss. This lichen (*Cetraria islandica* L.), the economic value of which has been discussed along with that of other lichens in Volume 2 of ECONOMIC BOTANY, yields a hemicellulosic gum on boiling that has value in cosmetic preparations and in the sizing of textiles, similar to that of Irish moss and the seeds of quince and psyllium. The whole lichens are pulverized by peoples of far northern latitudes and are incorporated into breads, gruels and other preparations. Considerable quantities have been used in the manufacture of sea biscuits which are said to be less liable to attacks by weevils than are other biscuits made only of wheat flour.

Miscellaneous Gums

Many cultivated trees, valued primarily because of their edible fruits, yield gums which show swelling properties and form jellies more or less transparent and uniform. In Europe, for instance, cherry gum is collected from *Prunus avium* L. and *P. Cerasus* L., the common cherry trees on the Continent, and at various times in the United States marketable quantities of the gum are offered as the result of off-season collecting by farmers and marketing organizations seeking profits from by-products of their fruit business. Supplies are not constant, but the gum finds application in pharmaceuticals. The cultivated peach, too, widely grown in the States from New York to Georgia, yields a hard reddish hydrophilic gum where the branches are bruised, or injured by boring insects. The same is true of plum trees. Gums collected from various fruit trees as well as the almond enter into the assortments of miscellaneous Indian gums and often constitute a mild form of adulteration of arabic ghatti and tragacanth. Syrian gum, sometimes designated as "carmenia" and not to be confused with the name "Syrian" as applied to flake tragacanth, is reputed to be the exuded masses from almond (*Prunus Amygdalus* Batsch.) and plum (*Prunus* spp.). It is often used locally in confectionery.

Other gums of minor commercial importance or used only locally, in their regions of usually crude collecting, for adhesives, as a size and cloth stiffener, in cosmetics and in pharmaceuticals are: angelique gum from *Dicorynia paraensis* Bentham, a large tree of northern South America; brea, or beira, gum from *Caesalpinia praecox* Ruiz & Pav., a small tree of northern Argentina; cactus gum from various species of *Opuntia* and *Carnegeia* in semi-arid districts of Mexico and the American Southwest; goma de cedro, cedro gum or cedar gum from the fragrant *Cedrela odorata* L. of the West Indies, the wood of which is used for cigar boxes; goma de guanacaste from the West Indian trees *Enterolobium cyclocarpum* Gris. and *E. ellipticum;* mesquite gum from various species of *Prosopis* in the American Southwest; mangrove gum from *Rhizophora Mangle* L., widespread in the tropics and semitropics; mimosa gum from several species of *Mimosa;* and a gum from the tree *Symphonia globulifera* of the West Indies and northern South America.

Seaweed Gums

The masses of seaweed that flourish to a depth of five fathoms in the coastal ocean waters of the world are raw materials for an increasing number of industries. For centuries they have been employed as agricultural fertilizers, human food, ingredients of pharmaceuticals and as a source of certain chemicals, namely, soda, potash and iodine by extraction, and, for a time, acetone by a fermentation process.

The extensive more recent utilization of these plants as a source of gum-like hydrophilic colloids under the names "agar", "carrageenin", "algin" and "alginates" had its origin in connection with World War I. These hydrophilic colloids are derived from two general groups of algae, namely, the kelps for algin and alginates, and the red algae for agar and carrageenin. The colloids thus derived have a number of similar properties, but also others which are physically and chemically different and which render one colloid more suitable than others for specific applications. Both groups of algae furnishing them have been discussed in two articles in Volume 1 of ECONOMIC BOTANY, and only certain aspects of their utilization will therefore be mentioned here.

Kelps. Kelps are the large ribbon-like brown algae, some of which are occasionally found washed ashore. They were formerly an important source of iodine. In 1883 E. C. C. Stanford, an English chemist, was attracted to this industry as a possible source of chemical by-products, and he pioneered in the field of extracting them. His attempts, however, were unsuccessful, but in the course of his investigations he obtained by alkaline extraction a substance with unusual gelling properties. When the material was precipitated, filtered and purified, he found it to be an acid and named it "alginic acid". This material has become the basis of present day utilization of kelps. It is a dry substance, not a liquid, and under microscopic examination is seen to be fibrous in a manner similar to wood pulp.

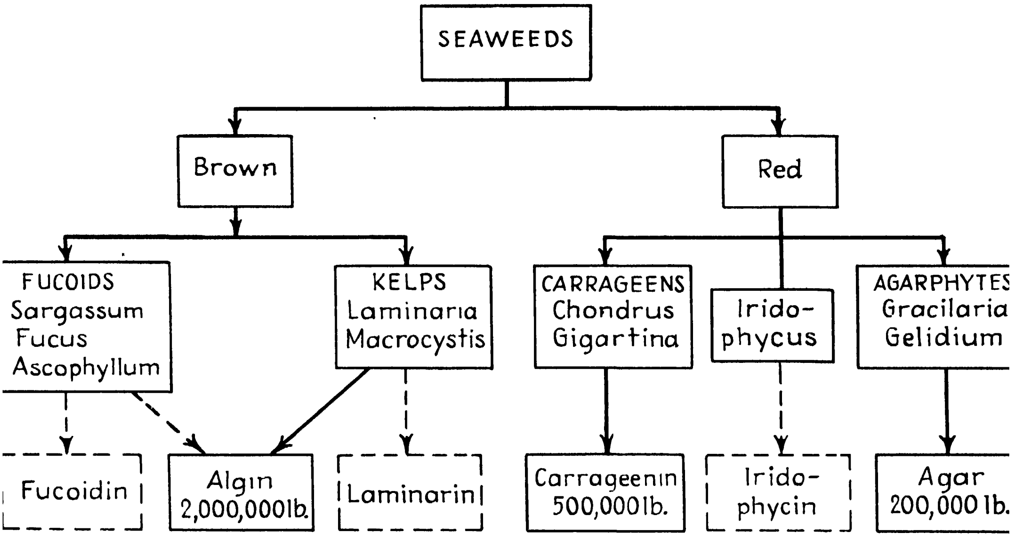

FIG. 7. The industrially important seaweed colloids and their sources. Broken lines indicate unimportant derivatives that may some day be of greater value.

Alginic acid, referred to industrially in its gelatin-like form as "algin", is today produced in the United States to the extent of more than two million pounds annually with a value of more than one and one-half million dollars. It may be in the form of crude pastes, as used for boiler-water treatment, selling for 5¢ to 7¢ per pound, or in purified flakes for 80¢ to a dollar or more per pound. The principal manufacturing establishments in the United States are the Algin Corporation of America, at Rockland, Maine, and the Kelco Co., at San Diego, California.

The Algin Corporation and other concerns processing the seaweeds in New England depend for raw materials upon collections, made along the coast up to Nova Scotia, of the horsetail kelp (*Laminaria digitata* Lam.) and the broad-leaf, or sugar, kelp (*L. saccharina* (L.) Lam.). Gathering in the shallow coastal waters is by power boats equipped with grapple hooks so as to operate at depths of 12 to 15 feet. Lesser quantities are collected from dories by hand dragging and raking as off-season work by fishermen. The best season for collecting is from June to the early part of December.

The Kelco Co. and others on the Pacific Coast depend primarily on the giant kelp (*Macrocystis pyrifera* (Turn.) Ag.) which grows over 100 feet in length and forms beds in the Pacific many square miles in area. The gathering mechanism is a motor-driven barge on which a modified under-water mowing machine is mounted. The machine has a horizontal blade, 10 to 20 feet wide, set four to five feet below the water surface. The kelp after it is cut is hoisted aboard by an inclined chain elevator. The cutter is mounted on the bow of the boat so that the cutting knife is ahead, and the boat at its beam is wider than the knife. The gatherer, or elevator, is directly behind the knife, and is chain-driven at speeds which are high enough to collect the kelp before the motion of the water carries it away. The edges of the elevator are equipped with knives so that the kelp does not jam at the sides and clog the cutter and elevator. Barge capacities of 300 tons are not unusual, and the kelp has been collected in amounts of several hundred thousand tons per year south of Point Conception, California. Kelp "farming" is carried on by cyclic cutting of the beds to permit natural replenishment.

Kelp beds are located below low-tide levels. Intertidal beds of other but much smaller brown algae, in the genera *Fucus* and *Ascophyllum*, are potential sources of seaweed colloids but have not yet acquired any commercial importance.

The extraction processes are rather complicated and are covered by patents. They all involve many steps and lead to the same ultimate products, namely, colloidal algin, calcium alginate, sodium alginate or other alginates. These products are commercially important because of their properties as emulsifying, suspending, jellying, thickening and bodying agents. One of the largest uses of algin in the United States is as a stabilizer for ice-cream. Its presence there induces smoothness of texture and prevents formation of ice crystals during storage. Algin finds wide application also in food products of a foam, jelly or emulsion nature, such as cakes, icings, chocolate milk and whipping cream.

Ammonium and sodium alginates have been widely suggested for casein emulsion paints. Sodium alginate, particularly in its cheaper and cruder form, is employed as an addition to boiler feed water to prevent incrustation. In this use calcium alginate precipitates are formed with the alkaline earth compounds in the water to give globular flocculent masses. These, with other compounds which settle out, give a soft pasty sludge which can readily be "blown down."

Algin and sodium alginate in many ways compete with the natural gums, such as arabic and tragacanth, in the preparation of greaseless lubricating jellies, hand lotions, sizing materials, pharmaceuticals and the many products which require thickening agents where viscosity increases are produced with small increases of solids contents. Being the product of chemical manufacture, the alginates are more consistently uniform than are the natural gums.

Considerable research on alginates for conversion into textile fibers has been carried forward. Such fibers do not compete with cotton or other natural fibers, or with rayon or nylon, for they readily dissolve when washed with soap or alkalies. They are of some interest in textile fabrication in designs which utilize the fibers in weaving and remove them by solution in finishing to obtain effects otherwise not possible. The preparation of fibers and yarns from alginates and the weaving thereof, with subsequent removal, is a relatively expensive procedure which can be justified only in special and costly fabrics.

In addition to the foregoing uses, application of alginates has been either established or investigated in the creaming of rubber latex, particularly the synthetic; as a coating for cheese, meat and other food products; and in toothpastes, lotions, pastes and polishes.

Red Algae. The important red algae utilized for extraction of colloidal material are Irish moss, harvested for carrageenin, and the other forms which are gathered for agar.

Irish moss (*Chondrus crispus* (L.) Stackh.) is known also as "carrageen", "carragheen", "carrageen moss", "carragheen moss", "pearl moss", "rocksalt moss", "killeen", "pigwrack" and by a number of other names. It grows in tufted clumps, two to ten inches tall, attached to rocks below the low tide water level, or in intertidal pools, along the American and European shores of the North Atlantic. In their natural habitat of sea water the plants display various shades of purple or dark green with purplish tints, and in shallow pools in rocks adjacent to areas of high water the color may be drab olive. When dry the plants are somewhat stiff, and the fronds, normally flexible, tend to be horny.

Harvesting season is from May to September and is formed with long-handled iron rakes, the operators working in dories and scraping the moss from the surface of submerged rocks. A good mosser will collect about 400 pounds in four hours during ebb tide. The moss is subsequently spread out on sandy beaches, repeatedly raked and sunbleached, or is bleached chemically with sulphur dioxide or other agents; it is also marketed in a black or unbleached form. There are many gradations of quality, and the cleaning and bleaching operation must be properly handled before the moss can be sold to extractors. The gelatinous material subsequently extracted by boiling water and known as "carrageenin" is used in the manufacture of pharmaceuticals, cosmetic soaps, paint, boiler-water compounds, in non-settling chocolate beverages (probably the greatest use), and in the brewing, textile, leather and other industries. Consumption of the dried seaweed in the United States for these purposes ranges from 800 to 1,200 tons annually, which means the gathering of 4,000 to 4,800 tons of wet weed. The value of the crop in Massachusetts, centering around the town of Scituate, was in excess of $100,000 in 1941, but from year to year the production varies widely.

Agar, which figuratively has hundreds of industrial uses and has an entire article devoted to it in Volume 1 of ECONOMIC BOTANY, is produced from red algae which are widely scattered off the seacoasts of Japan, China, Ceylon, Malaysia, Australia, Mexico, California, Lower California and North Carolina. In Japan it has been extracted, principally from species of *Gelidium*, since the seventeenth century, and prior to 1941 the United States depended almost wholly on this Japanese source for its agar, although there was one producer on the West Coast at San Diego, California. This Asiatic development accounts for some of its other names—"Japanese isinglass", "Chinese isinglass", vegetable isinglass", "seaweed isinglass", "Japanese gelatin", "bar kanten", "square kanten", "slender kanten" and others.

Three grades of Japanese agar are offered in the United States—Saghalien, Kobe and Yokohama. The first, from the Japanese part of Saghalien Island, is said to effect savings of sugar up to 30% in confections; it is imported in the least quantity and its price is the highest.

Kobe represents about 80% of the Japanese output and a far larger proportion of the American imports. Most of the Yokohama, or Shinshu, quality is consumed in Japan, not more than 30% being exported, principally to Europe. All three are available generally as strands, sheets, blocks, powder or in shredded form.

The seaweed from which the Japanese agar is extracted is collected from May to October by divers who make many descents during the day, cut the weeds free and return to the surface with bundles of them. The plants are then left on the beach three or four weeks to dry and bleach, and later are taken for manufacture to the mountains, for example, back of Kobe, where is found the right combination of cold nights and bright sunlit days to give the alternate freezing at night and the sun's thawing and bleaching action in the daytime. The manufacturing procedure involves cleaning the seaweed by beating and washing in cold fresh water until free of salt and most of the foreign matter. The material is then boiled for 30 to 40 hours to extract the glutinous matter and is allowed to settle undisturbed. Separation of grades is accomplished by scooping off layers without stirring; the top 70% usually furnishes the best grade. The solution is then poured into trays to cool and set, after which the jelly is forced through a perforated press. The resultant strips are next laid out to dry and bleach on shelves in the open or in covered open-sided sheds. The dried bleached product is sold either in strip form to the Japanese market or in ground form to the export trade.

By far the greater proportion of the American agar industry is located in the southern part of California. It began in 1919 with the founding of the American Agar Co. by seven Japanese in what is now Glendale. Mechanical refrigeration replaced the natural method of the Japanese procedure, and chlorine bleaching replaced that of the sun's rays. The raw material was *Gelidium cartilagineum* (L.) Gaill. from the San Pedro breakwater. Uneconomic operation as a result of too much hand labor resulted in commercial failure. In 1923 the plant was reorganized and the process mechanized by a successor who was responsible for American production from that year until 1926 but who terminated operations in 1933. In 1933 the United States Agar Co. was started in National City, Cal., to reprocess Japanese agar. This company subsequently became part of a fourth concern, the American Agar and Chemical Co., at San Diego, working on *Gelidium* from Mexico, Laguna, San Pedro and Redondo. A fifth outfit, Agar Products Co., of Los Angeles, lost its source of crude imported agar from Japan and turned to the nearby regions of the Pacific for raw material. In 1943 the Pacific Agar Co. began operations at Whittier, Cal., and increasing demand subsequently caused two factories in Mexico to come into operation. On the Atlantic Coast commercial quantities of *Gracilaria confervoides* (L.) Grev., suitable for agar extraction, are present in the region of Beaufort, N. C., and extracting factories have been set up at Beaufort, in New York and in Scituate, Mass.

The process of extraction and final preparation of agar for market includes many stages and careful manipulations, as depicted in Fig. 8. The chemistry of the substance is very complex and has not yet been fully worked out, but the material may be regarded as the calcium salt of a sulfuric ester of a colloidal carbohydrate complex.

C. K. Tseng, the author of one of the previous algal articles in ECONOMIC BOTANY, has estimated the distribution of agar consumption in the United States as follows:

TABLE 3.—DISTRIBUTION OF ANNUAL AGAR CONSUMPTION IN THE UNITED STATES (ESTIMATED)

	Pounds
Laxatives	100,000
Culture media	100,000
Bakery industry	100,000
Confectionery industry	100,000
Dental impression molds	75,000
Meat Packing	50,000
Emulsifiers	50,000
Cosmetics	25,000
Miscellaneous other uses	50,000
Total	650,000

Agar is a non-nutritive food, but is employed in food manufacture where bulk is desirable or where a hydrophilic colloid is useful because of its suspending, stabilizing, thickening or gelling characteristics. It serves to increase bulk in bakery products and is useful for low-calorie breads or biscuits for reduction diets for obesity or in nonstarch breads for diabetics. In dairy products, sherbets, water ices and frozen confections, agar, as well as the other natural gums and hemicelluloses, such as that of locust bean, serves as a stabilizer. Agar acts more quickly than gelatin but has a low whipping point, in which respect it is not so good as are the natural true gums. It is not recommended as a stabilizer for ice cream. Probably the major non-competitive use of agar has been in nutrient broths and culture media of biologists.

Modified Celluloses and Starches

By various treatments cellulose and starch are industrially converted into products possessing gum-like properties that make them useful in many of the ways in which natural gums are utilized.

Cellulose is insoluble in water and does not display any swelling characteristic, but when treated with alkyl halides, such as methyl chloride or alkyl sulfates, after preliminary chemical treatment, it is converted into a cellulose ether with gum-like applications. A number of these cellulose ethers have been prepared, and some of them are available in commercial quantities.

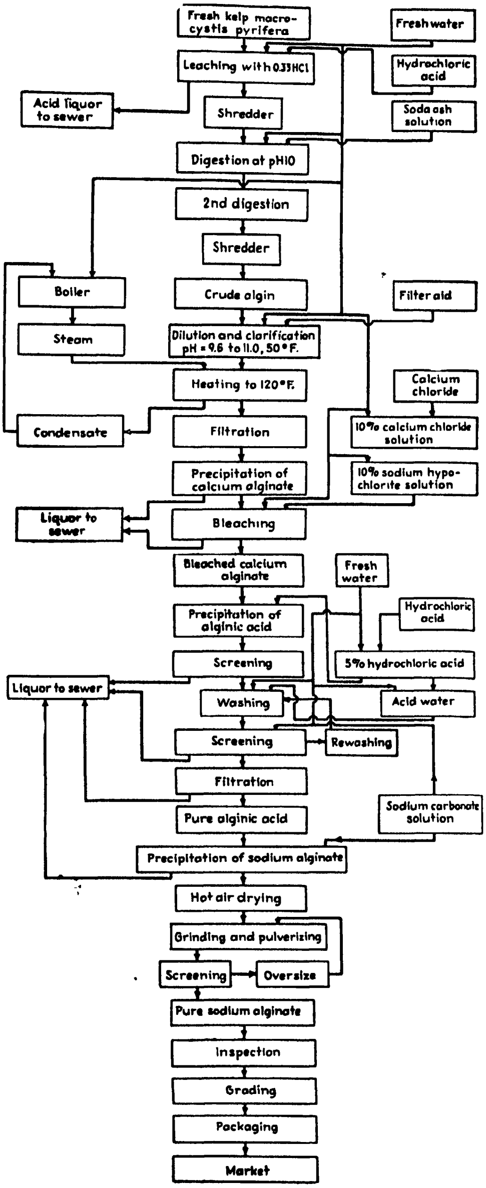

FIG. 8. Flow-sheet of the various operations in producing sodium alginate from the giant kelp, *Macrocystis pyrifera*, in California.

Methyl cellulose, for instance, has been suggested as a thickener or a mechanism for increase of viscosity for textile printing pastes in competition with modified starches, dextrins and natural gums. It has been introduced into the textile industry under the trade name Colloresine.

When cellulose is steeped in alkali metal hydroxide solution up to six hours, alkali cellulose is formed, and when this substance is acted on by monochloracetic acid, there is a conversion to a white, granular, tasteless powder, designated "carboxymethylcellulose". The sodium salt of this powder is known as "sodium carboxymethylcellulose", "cellulose gum", "sodium cellulose glycolate", and by the trade names Carboxy Methocel, Cellocel and CMC. This salt is readily dispersible in water or in alkaline solutions so that thick highly viscous sols are formed whose characteristics differ in degree and chemical properties from those of water-dispersible proteins, vegetable gums, seaweed colloids and hemicelluloses. Since it is a hydrophilic colloid it has been suggested for the usual water-dispersible gum applications, namely, as a protective colloid in emulsions to prevent separation of the phases, in adhesives, finishing and sizing agents in textiles, paper coating and others.

Modified starches are the dextrins and British gums. They are products of the action of heat or of heat and chemical agents on starch by dry processes, or conversion products manufactured by suspending starches in water or cooking them to jellies and acting on these with chemical agents, either cold or at high temperatures. Dextrin was first made in 1804 by roasting starch in an attempt to find a substitute for gum arabic and gum tragacanth which then already were largely used in industry. British gum reputedly originated as a result of a fire in a starch storage building at a textile plant near Dublin, Ireland, in September, 1821. Part of the factory was destroyed by fire, and the starch in storage was roasted to a brownish yellow color. When this material was mixed with cold water it no longer had the characteristics of starch but dissolved to a viscous gummy liquid. The results were duplicated by heating starch in a cooking pot over fire, and the manufactured material was henceforth known as "British gum".

Up to 1870 gums from *Acacia,* particularly from the Sudan, were almost exclusively used for the gumming of papers, envelopes and stamps. At the time of the Mahdist rebellion in the Sudan and the Sudanese campaign between 1884 and 1898, the supply of gum arabic was short and unstable. Prices rose to such an extent that substitutes were imperative, and dextrin from Germany relieved the situation. The raw materials for dextrins are the starches of corn, sago, tapioca and potato; smaller amounts from other sources are also used. The dextrin products vary considerably as a function of the raw material and of the manufacturing operations. While potato starch is thought of as the easiest one to convert, disagreeable odors are produced by thermal processing. Tapioca, or cassava, starch is free from this objection in that the dextrin made from it is in most cases odorless and tasteless while giving good adhesive strength, solubility, color, viscosity and clarity. It is the dextrin used almost exclusively by the U. S. Bureau of Engraving and Printing as an adhesive on postage stamps. When sago starch has been refined by washing or chemical treatment, satisfactory dextrin may be produced from it. It is claimed that the dextrins from cornstarch are not quite so good for some specialized purposes as that from tapioca or purified sago, but for most applications cornstarch dextrins are competitive with those from other sources.

The trade differentiates between dextrins and British gums in that the latter give higher viscosity dispersions, very thick masses or even non-flowing pastes. Some of these characteristics are owing to the presence of only partly converted starch. British gum may be made by simple thermal processing of starch without the use of a hydrolyzing agent, or with amounts much smaller than are employed for the preparation of dextrin. Typical hydrolizing agents are mineral acids—hydrochloric, nitric, sulfuric or mixtures of them; organic acids, *e.g.*, oxalic and formic; or halogen acids including hydrobromic. Acid salts and alkaline earth salts are also used as hydrolizing agents. British gums are usually somewhat darker than dextrins, being brown and often having a distinct burnt odor. Dextrins are often made from single starches, while British gums are commonly produced from mixtures of starches of various sources.

Gums in Cosmetics and Pharmacy

In the fields of cosmetics and pharmacy the hydrophilic colloids are used because of their mucilaginous or oily nature and their property of soothing enflamed or abraded membrane or skin and protecting them from irritation. In this capacity they are demulcents, or emollients. In lotions, ointments, pastes, salves, face creams and other cosmetic preparations they are suspending and emulsifying agents. Their quality of forming films upon evaporation, along with their ability to be plasticised or softened by other components, accounts for their presence in hair lotions, permanent waving compounds and bandoline.

The Pharmacopoeia of the United States lists gum arabic under Acacia; Agar; flaxseed, or linseed, as Linum; acacia mucilage as Mucilago Acaciae; tragacanth mucilage as Mucilago Tragacanthae; and tragacanth as Tragacanthae. The National Formulary lists Chondrus, Irish moss, Carrageen, Dextrinum Album and British gum. A number of unofficial lists, largely connected with the cosmetic arts, include cydonium, or quince seed; and karaya as Indian Tragacanth or Gum Sterculia. Other unofficial pharmaceutical listings include Psyllium which is in the British Pharmacopoeia Codex of 1923.

In principle the gums are interchangeable in their many uses ranging from laxatives to hair-wave lotions, but some of them are better suited than others to certain of these outlets.

Gums in Paints and Other Coating Compositions

Ancient Hebrew texts mention the decorator who used soured milk, the important constituent of which for that purpose is casein, and since the latter part of the nineteenth century factory-made casein paints in powder form have been sold in the United States. In recent years, however, and only after much development work, hydrophilic colloids and modified celluloses have found use in the paint industry in place of casein. The colloids are alginic acid and its sodium and ammonium salts, and the modified celluloses are sodium carboxymethylcellulose, aluminum carboxymethylcellulose and hydroxyethylcellulose. They do not constitute a major ingredient in the formulation of water paints, but nevertheless are of importance because of their stabilizing effects on emulsions of paints, waxes and numerous other products. In these uses they serve as thickeners, protective colloids or as film formers. As film formers with no modifying agents added, their use in the paint field is limited to a few special items, such as binders in fire-resistant paints where water-resistance is not essential.

The alginates have been incorporated in asphaltic paints and varnishes, shellac emulsions and waterproofing compositions in an emulsified form. Gum arabic has been employed in paints as a glaze and for emulsifying oils, and other kinds of protective coatings have included natural gums in their make-up.

Gums in Textile Operations

Although natural gums have many uses in the textile industries, starches and dextrins find much greater use in the same applications, and frequently the gums are used as a supplement to starch, chiefly to toughen the starch film. Whichever are used, they are employed in two capacities—as thickeners and as sizing.

Textile color designs are obtained either by weaving or knitting colored yarns into the material, or by printing. In printing, the woven cloth, after being de-sized, bleached, mercerized or dyed, and dried, is printed upon by a variety of methods. Most of them, including the most important one, roller or machine printing, require color pastes which consist of thickeners, water, dyes, mordants, dyeing assistants and other ingredients. The thickeners fall into two broad groups. In one are those used solely as thickening agents and later removed as completely as possible from the fabric. Their function is to act as vehicles for carrying the color to the cloth and to prevent spread of the color by capillarity beyond the desired areas. They must not, however, have any affinity for the colors or mordants with which they are mixed; otherwise, on being subsequently washed out of the printed fabric they will carry along much of the color. Arabic, Senegal, tragacanth, karaya and locust bean gums, starch, flour, dextrin, British gum and sodium alginate are in this group. The other group acts as both thickening and fixing agents, remaining on the cloth as an integral part of the finished color. In this group are albumen and casein, non-plant materials, which are both coagulated by heat. By steaming they change to an insoluble form and fix the dye on the fiber.

Formulation of the printing color paste must fulfill requirements of a range of viscosities, body and other characteristics. This requires skill in selection of the ingredients and in the formulation. The printing paste must fill the engravings of the design rollers and permit rapid removal of excess. The paste must be pressed into the cloth, yet remain within the limits of the desired pattern, and it must permit the color to be fixed. The ability of a printing paste to give a fine line, a delicate design, lightly engraved blotches, heavy blotches, a blending of colors, a sharp definition of colors, penetration of color to the back of the cloth, and a great many other desirable qualities is in large measure dependent upon the thickening used. For cotton the natural gums are too expensive, and the cheaper starches and British gums are used.

Sizing, or slashing, consists of the treatment of warp threads with a solution that forms a thin layer of binding material on the yarn in order to hold together all loose fibers and strengthen the yarn for weaving. The principal gums used in cotton sizing in order of importance are locust bean, karaya, tragacanth and arabic; also the starches of corn, potato, tapioca, rice, wheat, sago and sweet potato. Locust bean is the most used, followed by karaya.

Turkish or Oriental Tobacco

Commercial production of Turkish varieties of tobacco in the United States is still a thing of the future, but investigations in that direction are being conducted.

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Historical Introduction

None of the many species of *Nicotiana,* except *N. rustica* and *N. tabacum,* is grown for the production of commercial tobacco, and such use of *N. rustica* is very limited, since it is utilized mainly as a source of nicotine for insecticides. The several botanical varieties and all the agronomic varieties of "ordinary" tobacco grown throughout the world, some of which are strikingly dissimilar in appearance, belong to one species, *N. tabacum.* This species, therefore, must be considered as an exceedingly plastic one, and its plasticity may be a result of its being a natural hybrid, as indicated by genetical evidence. Moreover, as is widely appreciated, the agronomic varieties have arisen partly by selection and hybridization and partly by adaptation to environmental differences in different parts of the world. As might be anticipated, certain of these varieties are also radically different from all the others in physical and chemical properties. Consequently all those having closely similar properties and similar use in manufacture and in international commerce belong to the same type. Commercial types, to mention a few only, bear such names as the following: Burley, flue-cured or Virginia, cigar filler, cigar wrapper, sun-cured, and Turkish or oriental.

The oriental tobaccos, which include several hundred varieties, are grown in a region generally known as the Near East, comprising Greece, Romania, Bulgaria, Russia (Crimean area), Turkey, Iran, Irak and Egypt. It is not definitely established when tobacco culture was first initiated there, but it probably dates from early in the 17th century. Oriental tobaccos were never greatly in demand in world markets during the succeeding 300 years, and, during this long period, the expansion of the tobacco industry in the Near East was slow and quite uneventful.

Until approximately 30 years ago the quantities of oriental tobacco imported into the United States each year were relatively small, and such tobacco was employed here almost entirely in the manufacture of all-Turkish cigarettes. Then, just prior to the outbreak of World War I, to dispose of accumulated stocks, certain manufacturers blended oriental tobaccos with domestic types to make cigarettes. Such blended cigarettes found immediate public favor because of improved aroma, better combustibility and better flavor. In fact, the popularity of blended cigarettes and blended pipe tobacco has increased rapidly each subsequent year. Coincidental with the rapidly increasing demand for blended smoking tobacco in the United States, there was a marked increase in tobacco production in the Near East, to the extent that when World War II began the annual crop there exceeded 100 million pounds. A large proportion was being purchased each year by American tobacco manufacturers. As a consequence of the lack of facilities for shipping and the radical changes in price structure occasioned by the war, the entire oriental tobacco industry became greatly disrupted. Whether it can again be stabilized to approximate pre-war conditions remains quite unpredictable and problematical.

During this period of rapid expansion, just mentioned, American and foreign tobacconists fostered the idea that tobacco having the qualities of oriental tobacco cannot be grown in any other portion of the world. A variety of reasons in support of this opinion was assigned. By and large, these reasons centered around obvious differences between different tobacco-growing regions, such as those of soils, prevailing temperatures, distribution of rainfall, and techniques of curing and subsequent processing. Published information, based on adequate experimental studies, regarding the production of oriental tobacco in the Near-East is meagre. At least such information as has come to hand, when critically appraised, has little value in determining the possibility of producing tobacco having the features of the oriental type in any region outside the Near East. Unfortunately the impact of opinions expressed by tobacconists and others with commercial interests to the effect that such tobacco cannot be grown elsewhere was tremendous, especially when their statements were employed as propaganda. In extenuation it may be said that actual field trials, involving the expenditure of thousands of dollars, have been made to grow oriental tobacco in the United States, and the results, showing lack of success, have been cited to support these opinions. When, however, the procedures involved in these trials are critically examined, the work must be appraised as quasi-scientific and quite inadequate, mainly for the reason that it shows lack of evidence of having been based upon fundamental knowledge of the tobacco plant itself, of its culture and of the factors correlated with "quality" in Turkish tobacco.

Elsewhere throughout the world, except in Rhodesia, no serious attempts have been made to cultivate Turkish tobacco. There in recent years the venture has attained the proportions of being commercially successful.

Experimental Findings

In 1939 a group interested in tobacco research, of which the writer is a member, decided to undertake a study to determine whether tobacco of the Turkish type might be grown in the southeastern United States, but only after having carefully considered the foreseeable difficulties involved in such a venture and the possible economic consequences. This study, employing both field and laboratory experiments, has now been in progress for nine years. In brief it has been established that tobaccos quite like those imported from the Near East can be grown in the Piedmont and Mountain Areas of Virginia, North Carolina and South Carolina. The rationale underlying all the procedures employed, just as in the production of other types of tobacco, has not been resolved. Such definitive progress as has been made has been recorded, in part, in some detail (1–8). It seems best at this point to state categorically the most significant of these findings and to leave until afterward their application to cultural practices. These findings include the following:

1. Varieties of tobacco long established in the Near East yield a product that is superior in quality to that from varieties that have been introduced there recently. Varieties long grown in the Near East, if planted in the United States, are found to be entirely unlike any commercial varieties now being

planted here. On the other hand, varieties recently introduced into the Near East, if planted in the United States, are recognizable as quite like some of the varieties now being grown here.

2. There are four primary groups among oriental tobacco: Samsoun, Smyrna, Kavalla, Xanthi. Experienced tobacconists, when given cured leaves to examine, not only readily distinguish between these groups but are able also to identify by name many of the varieties within each group.

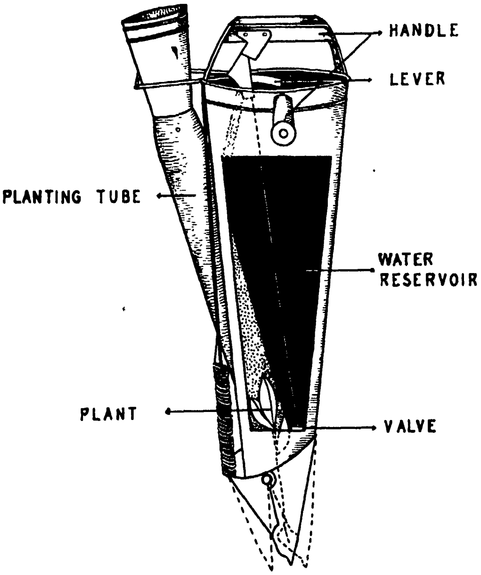


FIG. 1. A hand-planter, useful for transplanting tobacco seedlings. Survival is insured by watering each seedling while transplanting.

3. Considerable differences, as in height, time of maturing, leafiness, leaf shape, type of insertion of leaves and hairiness of leaves, exist between plants within any named variety of oriental tobacco. Kinds that are different in these features from the parent stock have been obtained by selection, but it has not been possible to secure complete similarity of progeny.

4. The elements of which "quality" in different types of tobacco is constituted, or the features with which quality is correlated, remain only partially analyzed and evaluated. But from the viewpoint of manufacturers, quality in oriental tobacco includes, as essential characteristics, aroma, combustibility and flavor.

5. Seasonal factors modify quality in oriental tobacco. Rains in excess when accompanied by continuously overcast skies unfavorably affect the development of tobacco having best quality, whereas the production of vintage crops is promoted by dry hot seasons.

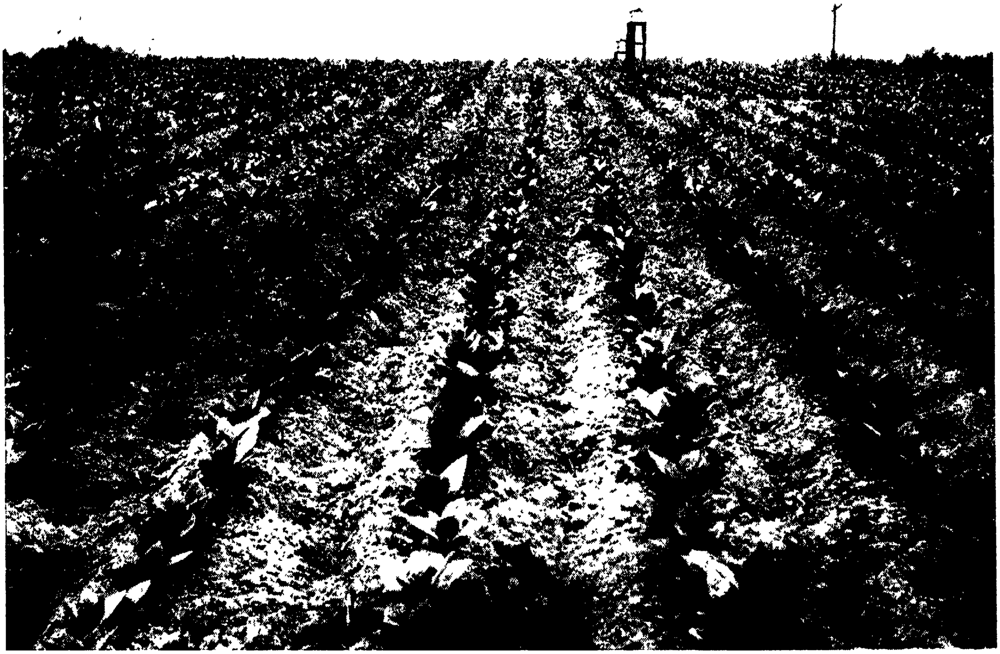
6. The rate of growth of oriental tobacco for development of best quality is continuously slow throughout the entire season. When such growth is graphically represented, the growth curve is sigmoidal, although it tends to approximate a straight line.

7. Varieties of oriental tobacco differ strikingly in duration of the growth period, some requiring 30 to 40 days longer than others to reach complete maturity. In general, late-maturing kinds are taller, more robust, have the largest number of leaves, and when cured, their leaves are the most aromatic, but they bear the smallest number of flowers and capsules.

8. Oriental tobaccos are best harvested by removing the leaves as they mature, a few at a time, beginning with the lowermost and progressing upward on the stalk. Harvesting in this manner is called "priming." The leaves are air-cured, and curing is customarily hastened by exposure to sunshine.

9. To date there are no analytic procedures by which to gauge maturity. It is determined empirically. Immature leaves and over-mature ones, when cured, differ markedly from mature ones in texture, color and aromatic properties.

10. The uppermost leaves are generally of the best quality, and those borne near the base of the stalk are of poorest quality.



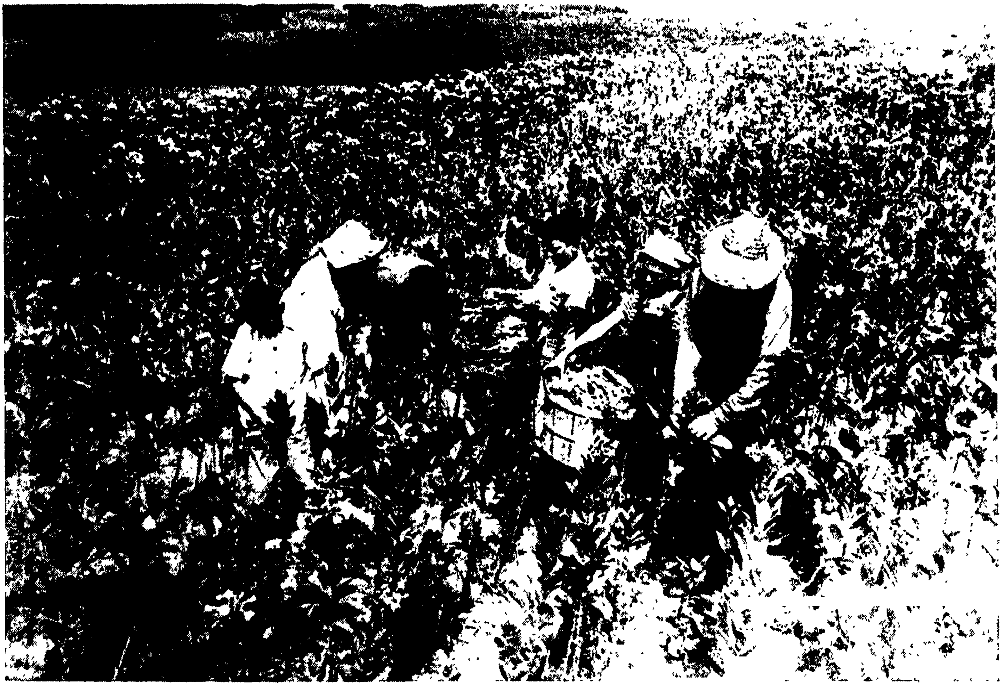


FIG. 2 (*Upper*). A field of oriental tobacco about four weeks after transplanting.

FIG. 3 (*Lower*). Harvesting oriental tobacco by removal of leaves as they mature.

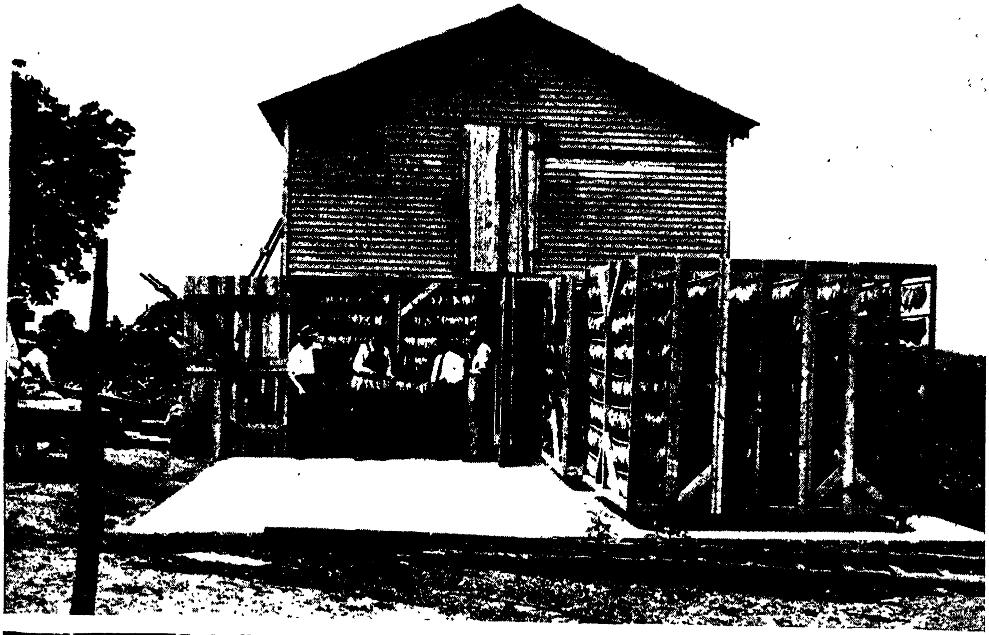


FIG. 4 (*Upper*). Curing and storage barn. The racks are moved out of the barn to facilitate curing, and are returned at night or to avoid injury from rain.

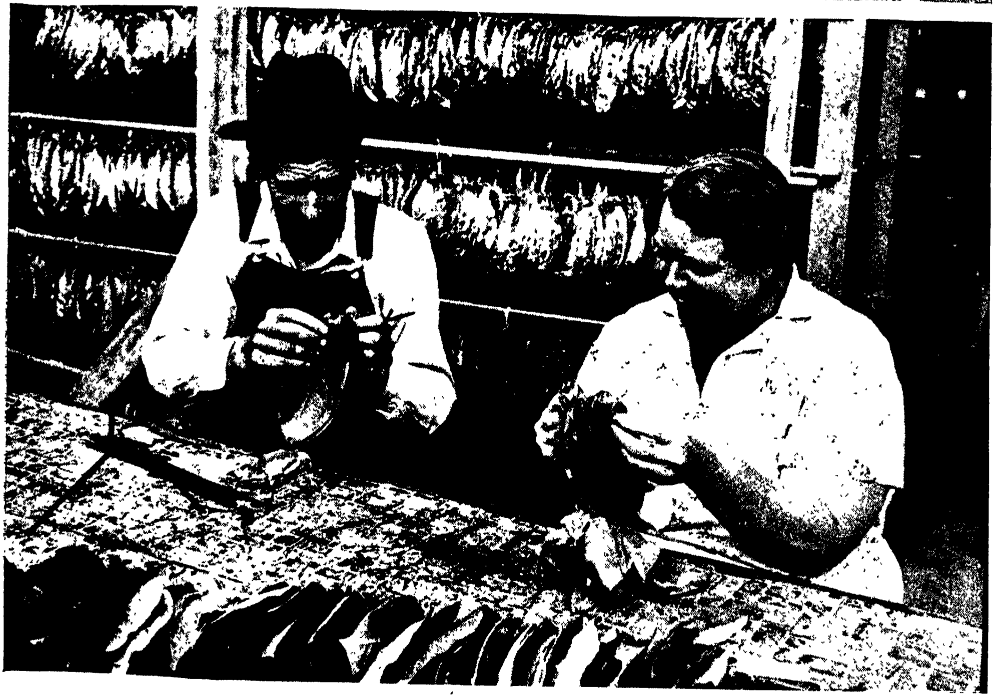


FIG. 5 (*Lower*). Stringing oriental tobacco by use of a long needle. In the background are strings of leaves attached to sticks.

11. Leaves having the largest surface area are produced along the median stalk region, and are progressively smaller toward the extremities.

12. Each leaf, except a few juvenile ones near the base, on any plant, regardless of leaf size, tends to have the same number of glandular hairs. As an outcome the population density of such hairs is greatest on the smallest leaves, *i.e.*, those borne near the top of the plant.

13. Aroma of oriental tobacco seems to be traceable primarily to the exudate synthesized by glandular hairs. The chemical nature of this exudate is not fully known, but it is a resinous complex containing ethereal oils which presumably undergo polemerization and oxidation slowly during curing and aging.

14. The density of hair population is heritable, but the number of hairs per leaf may be modified by environmental factors, such as spacing of plants and illumination. It follows that volume or quantity of aroma is to a degree controllable. There is evidence to indicate that quality of aroma is also controllable but to a lesser extent.

15. The differences in quality of leaves borne at different levels on the stalk are not traceable alone to differences in density of population of glandular hairs. There are also differences the causes of which are internal.

16. The removal of leaves in harvesting disturbs the leaf-stem-root balance and in consequence upsets the physiologic equilibrium of the entire plant. Compensatory adjustments or changes are therefore induced in the leaves remaining to be harvested. Such changes become progressively greater with each successive priming of leaves. As a consequence the leaves of each priming are chemically different from those of all others.

17. Oriental tobacco is not topped, *i.e.*, the flower stalks are not removed, because the physiological unbalance induced by topping results in undesirable physical and chemical modifications in the leaves.

18. Internal factors which regulate metabolism govern vegetativeness and reproduction in a tobacco plant. These factors are anti-complementary or oppositional. The point of inflection of the growth curve marks the stage at which the opposed factors are in balance. The factors are unbalanced in favor of vegetativeness during development of the leaves borne along the lower portion of the stalk, and in favor of reproduction during development of the upper leaves.

Application of Findings to Field Practices. Planting. Proper spacing of plants in the field is very essential in growing oriental tobacco because the plants when closely spaced grow slowly, and as a result the leaves are of small size, of desired texture and have the optimum hair population and chemical composition. The number of plants per acre should range between 50,000 and 70,000. If the distance between rows is 20 inches and that between plants within the row is 5½ inches, the number of plants per acre will approximate 60,000. Each plant, depending upon the variety, produces from 20 to 40 leaves, and from 700 to 2,000 cured leaves are required to weigh a pound.

Soils and Preparation of the field. The fertility level of fields in which oriental tobacco is to be grown is also an important practical consideration. A slow growth rate that can be controlled may be obtained by employment of infertile soils. For these requirements clay soils have been found preferable to sandy soils. Then, to provide a supply of essential minerals requisite for satisfactory yield and quality, well decomposed manure, six to eight tons per acre, may be applied. In general, when the

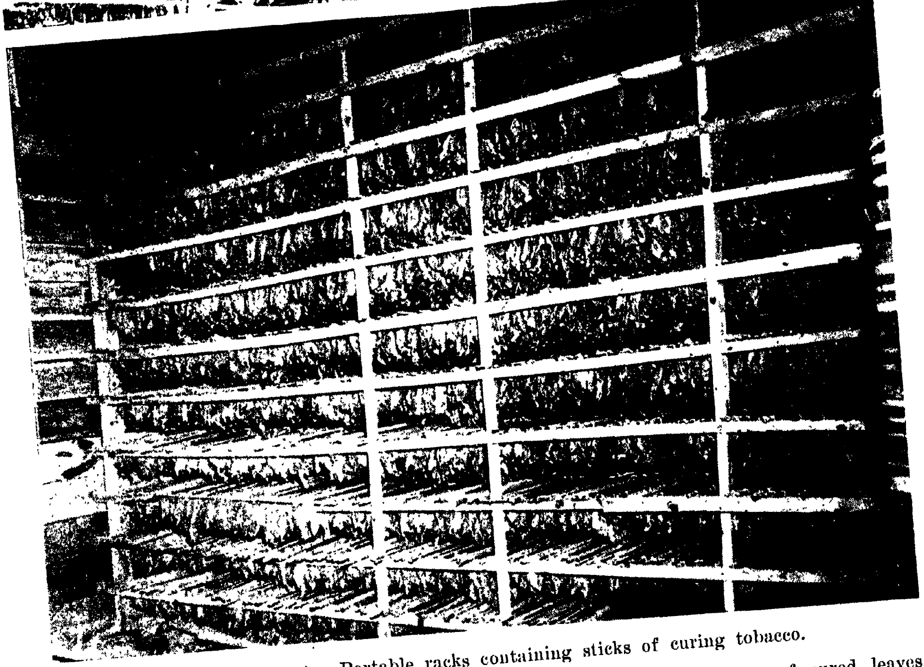
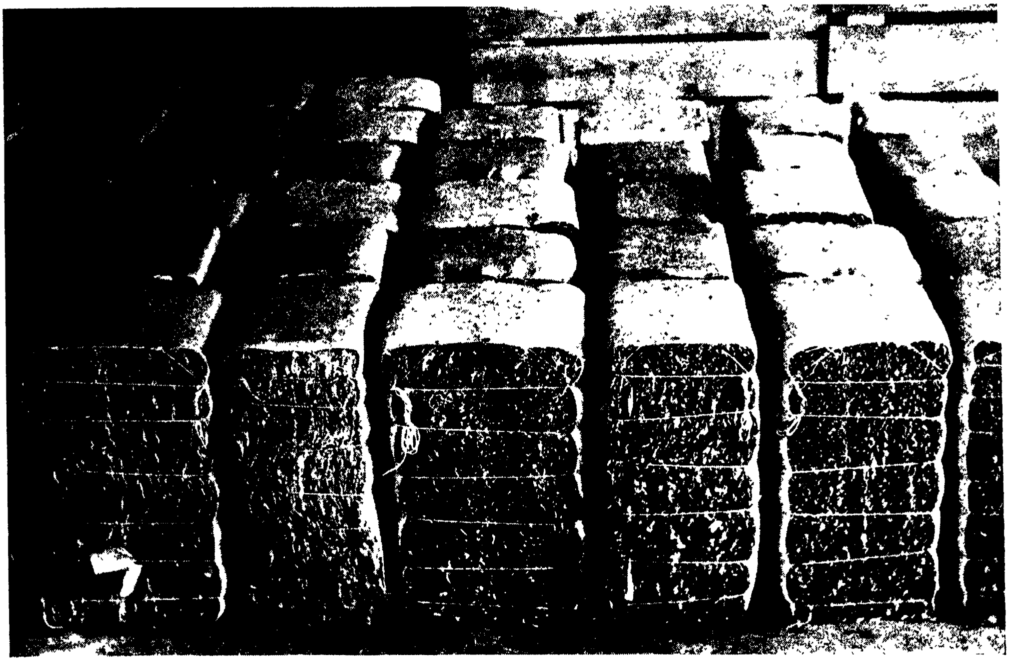


FIG. 6 (*Upper*). Portable racks containing sticks of curing tobacco.

FIG. 7 (*Lower*). Racks showing proper placement in storage of sticks of cured leaves. Such tobacco is ready to be baled.



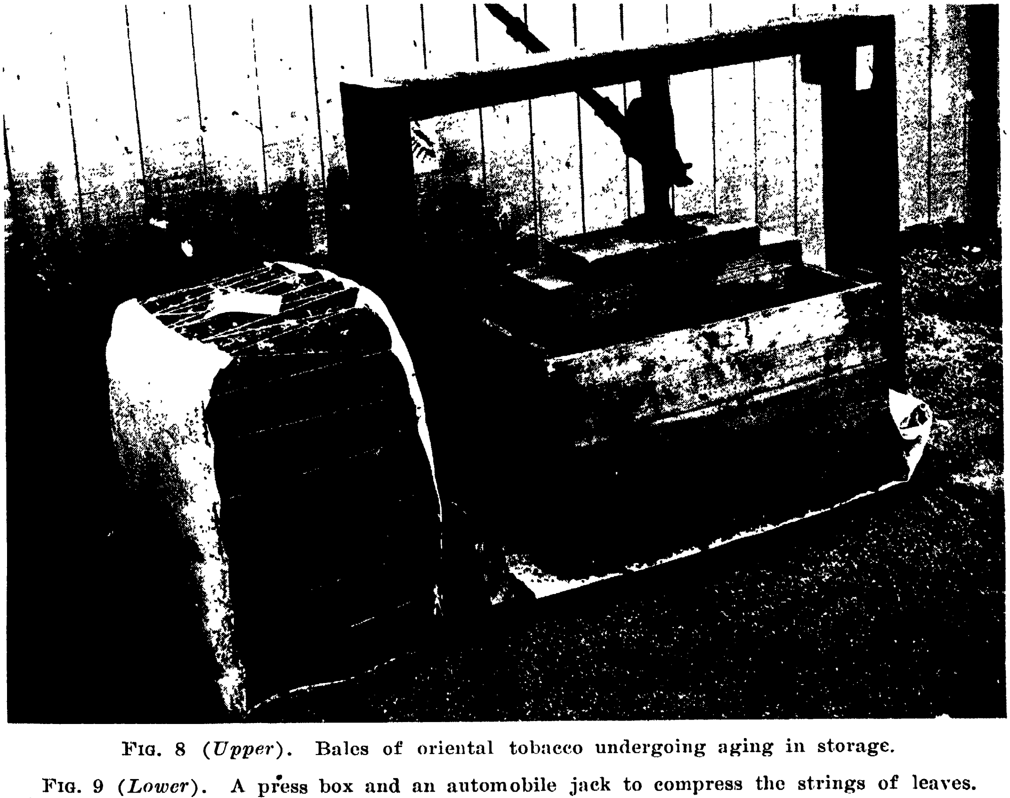


FIG. 8 (*Upper*). Bales of oriental tobacco undergoing aging in storage.

FIG. 9 (*Lower*). A press box and an automobile jack to compress the strings of leaves.

fertility level is raised by use of mixed commercial fertilizer, the quality of the cured leaves is undesirable. To supplement manures, however, potash in the form of sulfate of potassium, using 80 to 100 pounds per acre, is advantageous. In the presence of sufficient potassium cuticularization of the leaves is increased and quality, especially texture and combustibility, is thereby enhanced.

For best results the fields should be plowed, disked and manured well in advance of planting to the extent of establishing a good state of tilth. If the soils are thus well prepared, two or three cultivations during growth of the crop should be sufficient. A hoe or hoe-fork is best suited for use in the first cultivation which should be made 10 to 15 days after transplanting. Subsequent cultivations are best made by use of a horse-drawn cultivator of a kind having two or three bull-tongue points or shovels.

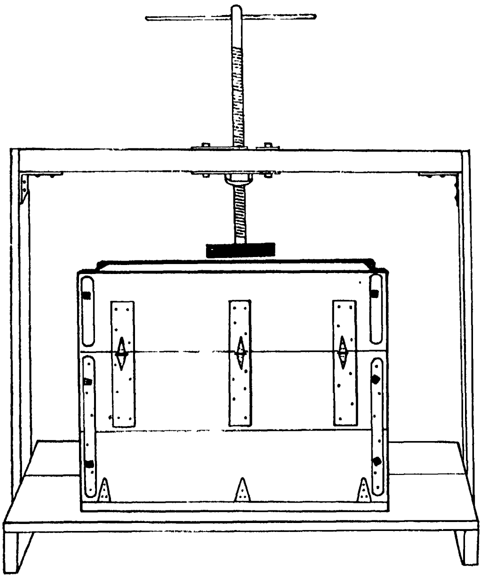


FIG. 10. Diagram of a screw press and collapsible frame of a kind that is adapted for use in baling oriental tobacco.

Harvesting and Curing. The lowermost leaves will be sufficiently mature to harvest approximately 50 days after transplanting. The topmost leaves may not be harvested until four to eight weeks later, depending upon the variety of tobacco and the prevailing weather. The leaves must be threaded onto strings as soon as possible after they have been harvested. In so doing a long needle is used to pierce the midribs. The strings of leaves are next attached to sticks or laths which are closely hung in a shed to permit the leaves to wilt and yellow. Proper wilting and yellowing are dependent upon maintenance of suitable relative humidity of the ambient air within the shed and of controlling air movement. If the humidity is too low and the air circulates too freely, the leaves will not yellow satisfactorily but will become dry; at the opposite environmental extreme, droplets of moisture may accumulate on the leaves, and and the tissues will then become discolored.

Wilting and yellowing should be accomplished after two days, whereupon the leaves should be placed on curing racks and exposed to direct sunshine. Curing requires from five to ten days if the weather is favorable. Unless the leaves are protected against dews and rains during curing, they become darkened. For this reason it is essential that the curing racks be portable or readily movable so that the curing tobacco can be moved under shelter at night and also during daytime when rains are imminent.

Once the leaves are thoroughly cured, the sticks of tobacco may be removed from the racks and placed in dry storage. Storage is suitable only if it is well ventilated and if the tobaccos remain dry during wet weather. Otherwise the tobacco may become damaged by molds.

Baling and Grading. Specially constructed frames or boxes and a mechanism for pressing are necessary for baling. At time of baling the moisture content of the leaves should be such that they will not break on being handled, and yet they should be sufficiently dry to rattle. In baling the strings of leaves are compacted into the box and the bulk is then covered with burlap. If growers bale in this fashion the bales may then be moved to a factory. It is advisable to keep the primings separate, for by so doing grading at the factory is greatly facilitated. There the bales are opened, the strings are removed, the leaves are sorted, and again the tobacco is baled and stored to permit aging. During aging the bales are variously turned and stacked, a process called "manipulation". Aging requires for completion a period of a year to several years.

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Utilization Abstract

Soybeans. In late 1947 the Chemical Division of General Mills, Inc., initiated commercial production of polyamide resin from soybean oil. This new product "is a tough, heat-resistant plastic, used primarily as a water and vapor sealer and as an adhesive surface coating for paper." It was the Northern Regional Research Laboratory of the United States Department of Agriculture that pioneered the manufacture and industrial utilization of polyamide resin from vegetable oil. In 1943 that organization developed a polyamide popularly known as Norelac, worked out unit processes and practical flow sheets for manufacturing the product and uncovered many potential uses for it. General Mills entered the picture at that time by launching a research program directed toward improving Norelac and by making pilot plant quantities of the resin available to industry.

"During World War II, this polyamide resin served as an ingredient in some of the hot-dip stripping compounds which protected Army and Navy equipment and spare parts against corrosion during overseas shipment. Applied while hot, these compounds hardened to a solid film as they cooled and could be easily stripped off when the equipment reached its destination".

The greatest peace-time application of polyamide resins is in packaging. (*A. G. Hovey, Chemurgic Digest 7(1): 18. 1948*).

Coir Dust or Cocopeat—*A Byproduct of the Coconut*

This material, now being produced commercially in Puerto Rico, has value as a mulching, rooting, soil-conditioning and seed-germinating medium.

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For hundreds of years natives of tropical countries have gathered coconuts (*Cocos nucifera* L.) and dehusked them in order to get at the edible contents of the nut itself, normally discarding the husk. In some countries, notably India and Ceylon, the husks have at times been soaked in water to loosen the fibers of which they are exclusively composed, and the fibers have then been separated by pounding for manufacture into cordage; or they have been separated by holding the husks against a revolving wheel armed with spikes. The latter method produces very short fibers unsuited for cordage but adaptable to conversion into the familiar coco door-mats abundantly imported into the United States. A byproduct of this short-fiber production is a mass of tiny, brown, irregularly shaped particles, known in the British Empire as ''coir dust''. Because the term ''dust'' to most people implies an undesirable quality and has no connection with the coconut, and because this so-called ''dust'' has many characteristics of horticultural peat, it is here suggested that this valuable material be known as ''cocopeat''.

A search of the literature has disclosed only four authors, working chiefly in India and Ceylon, who discuss its use. One of them recommends it, when well leached, to increase the organic matter content of potting soils. He also notes its slow decomposition and beneficial mechanical effect in improving soil drainage. Another mentions its use for bedding animals, as a packing material for nursery stock and for insulation. A third author describes its use in the fertilization program for coconut plantations where it is placed in shallow trenches around trees to which animals are tethered, absorbing their urine and holding it for use by the tree.

In the only known publication dealing solely with the material, analyses show that it contains less than one percent of any of the major nutrients and thus indicate that it can not be sold as a fertilizer. These data also show that it contains approximately 40 percent lignin and only 12 percent pentosans. The author of them interprets this low pentosan-to-lignin ratio as an indication of extremely slow decomposability and suggests that the decomposition process could be stimulated by addition of nutrients and materials high in pentosans, such as grasses. He also showed its ability to improve the moisture-holding capacity of sandy soils when, by adding only two percent of cocopeat to a sandy loam, the moisture-holding capacity of the soil was increased from 24.3 to 33.2 percent, or nearly 40 percent. This increase is not surprising, for he found the moisture-holding capacity to be over 800 percent on a dry-weight basis.

Until recently cocopeat was practically unavailable in the Western Hemisphere.

A modern coconut fiber factory established in Mayaguez, Puerto Rico, is now producing this material in large quantities as a byproduct. Although only preliminary tests have been made with it at the Federal Experiment Station in Puerto Rico, it has been found sufficiently useful to practically eliminate the necessity of importing peat for horticultural uses.

An analysis of cocopeat from the above source is reported in Table 1. A sample representing the oldest material available which had weathered approximately four years in the open was very similar in composition, indicating extremely little decomposition. Cocopeat is fairly well supplied with iron and manganese, and has been shown to contain 17 parts per million of water-soluble manganese, 33 ppm of exchangeable and 63 ppm of reducible manganese. The iron content was 100 ppm of water-soluble, 78 ppm of exchangeable and 81 ppm reducible iron. It is only slightly acid, with pH values ranging from 5.7 to 6.7(2).

TABLE 1

MINERAL COMPOSITION OF THREE FRESH SAMPLES OF UNSCREENED COCOPEAT[1]

Sample	*Ash*	*Ca*	*Mg*	*K*	*P*	*N*
	%	%	%	%	%	%
1	2.39	0.42	0.63	0.82	0.07	0.11
2	2.45	0.39	0.70	0.25	0.09	0.11
3	2.48	0.31	0.65	0.84	0.09	0.11

[1] Analyzed by R. Fernández Pol, Collaborating Chemist, Federal Experiment Station, Mayaguez, Puerto Rico.

As pointed out by Joachim, cocopeat is very slow in decomposing. It requires less frequent replenishing than most other mulching materials, but is gradually mixed with the soil by the action of worms and other soil organisms, eventually improving the physical condition of the soil.

Macmillan makes a special point of using well decomposed cocopeat, possibly implying the existence of something toxic in the fresh material. In order to test this point, a cylinder of fresh cocopeat three feet long and 14 inches in diameter was enclosed in fine-mesh chicken wire. Tap water was poured through the cylinder to leach out any soluble material. The leachate was used to water one of two flats of sand in which identical seeding had been made. The other was watered only with tap water. The results are shown in Table 2.

TABLE 2

HEIGHT OF SEEDLINGS GROWN IN SAND WITH AND WITHOUT WATER EXTRACT OF COCOPEAT 30 DAYS FROM SEEDING

Species	*Average height of seedlings*	
	With cocopeat extract	*With tap water only*
	Inches	Inches
Bauhinia purpurea L.	2.5	0.8
Bauhinia violacea Hort.	3.0	1.6
Sterculia apetala (Jacq.) Karst.	7.1	4.2
Couroupita guianensis Aubl.	2.1	1.1
Cassia spectabilis DC.	2.1	1.0
Erythrina berteroana Urban	2.4	1.2
Average height of all seedlings	3.45	1.65

It is evident that, quite contrary to causing any deleterious effect, the early growth of seedlings was stimulated by the cocopeat extract. The treated seedlings averaged 3.45 inches in height, while the untreated averaged only 1.65 inches. The percent germination was unaffected.

Cocopeat has been found to be a desirable material for mulching, especially if the short fibers are not removed. In the general landscape program on the Station grounds, plants of 15 species were planted near the end of the rainy season in the fall of 1947. The following winter and spring were exceptionally dry, even for Mayaguez, which normally experiences a well developed winter dry season. All the plants were mulched with a three-inch layer of cocopeat, and not a single plant died because of insufficient moisture, although none of the plants was watered except at planting. The only difficulty encountered with cocopeat for mulching is its light weight. When dry, or nearly dry, a sudden violent rain may cause sufficient run-off to literally float the mulch away. This difficulty can be overcome by using soil conservation measures or otherwise reducing surface water movement, and by applying a light layer of coarse sand or fine gravel on top of the mulch. Cocopeat has the great advantage over many mulching materials of being free of weed seed. Frequently weeds appear after mulching with cocopeat, but it has been found in these cases that the weeds came from seeds already on the surface, which sprouted because of the improved conditions after mulching. Some kinds of mulch, if partially dry, will absorb practically all of the water from a light shower, preventing it from reaching the roots in the soil below. Cocopeat, however, permits rapid penetration of a good part of even a small precipitation. This character is particularly important in regions experiencing chiefly light rains during the dry season.

Cocopeat mixed with heavy soil is particularly beneficial in improving its physical condition. The many porous particles and fibers assist in providing channels for aeration and drainage. On the other hand, sandy soils, which hold little water and nutrients, produce better crops when even small percentages of cocopeat are added because of the very high moisture-holding and nutrient-absorption capacity of this material.

The application of mulch on the surface of a clay subsoil at Mayaguez did not in itself affect the permeability of the clay. Infiltration studies indicated no increase in the rate of soil water intake six months after an application of either one or two inches of cocopeat, but the mulch of cocopeat was able to absorb and hold a tremendous amount of water on the soil until it could soak in (5). The studies show an absorption rate by the cocopeat equivalent to 94 inches per hour, or more than 300 times that of the soil below in these particular trials. It was determined that the water-holding capacity of this cocopeat was 75 percent by volume. In other words, a three-inch mulch of dry cocopeat could control the runoff of practically all of a two-inch rain, regardless of the rate at which it falls.

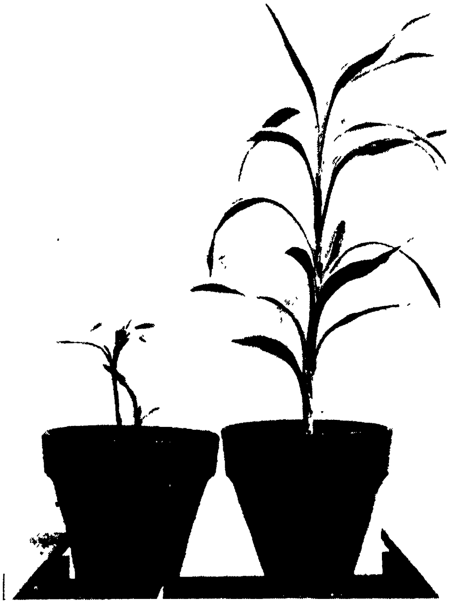

FIG. 1. The growth of *Dracaena sanderiana* Hort. in sandy clay soil 15 months old (left) compared to a plant of the same species in unscreened cocopeat 11 months old (right).

Cocopeat is also useful in propagating seeds and cuttings. Best results have been obtained for these purposes when the peat was mixed with other ingredients. For seed germination equal parts by volume of cocopeat, sand and compost have given good results. Cuttings can be rooted in a mixture of one part cocopeat and three parts sand. No difference was observed in the rooting of cuttings when the proportion of cocopeat varied from 25 to 75 percent by volume. Adding cocopeat to propagating sand has the advantage, besides reducing the frequency of watering, of making the propagating mixture soft enough so that cuttings can be pushed directly into the mixture without injuring the cut surface.

Unscreened cocopeat, containing short coconut fibers, can be used as a growing medium without other ingredients, as shown in Fig. 1. The danger in this case is from over-watering, but mixing it with sand and loamy soil will overcome this difficulty. Because of its high moisture-holding capacity such a mixture should be useful for those who like to grow plants in the home but tend to forget about regular watering.

Additional experimental work is necessary to establish the place of cocopeat in horticulture. The results so far have been very encouraging. Its use for mulching, soil conditioning and propagation is worthy of trial by all who are interested in trying new horticultural products.

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Utilization Abstract

Margarine. Margarine "is a combination of refined oils, pasteurized and cultured skim milk, salt, and lesser ingredients, processed to desired plasticity, melting point, and flavor". Roughly a third of America's table spread consists of margarine, close to 700 million pounds of which were produced in 1947. The origin of the name lies in the Greek word "margarites", meaning pearl-like.

"Approximately 99 per cent of the oils used are vegetable oils—cottonseed oil, soybean oil, peanut oil, corn oil, and miscellaneous other oils. Of these, cottonseed and soybean oils are the major products used. Last year, for example, cottonseed oil used in margarine manufacture accounted for 48 per cent of the total oils used, and amounted to approximately 223 million pounds of refined oil. This is the oil equivalent of about 3 million acres of cotton.

"Soybean oil accounted for 43 per cent of the margarine oil ingredients, totaling 201 million pounds of oil or the equivalent of about 1,170,000 acres of soybeans. Peanut oil contributed 3 per cent; corn oil, 1 per cent. The animal fats used in 1946 constituted only about 1 per cent, and were mostly beef fat or stearine". (*P. T. Truitt, Chemurgic Digest 7: 15. 1948*).

Grapes and Wine

About 20 per cent of the world's table grapes and 40 per cent of the world's raisins are produced in California, but less than 3 per cent of the wines of the world.

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The grapevine has furnished man with food and drink from the dawn of civilization. Noah planted a vineyard. Grape and wine production were figured in the mosaics of the earliest Egyptian dynasties. Later the Roman statesmen and naturalists—Cato, the Plinys, and Columella—wrote of the grape and of wines. They described many varieties, listed numerous types of wine, and gave directions for the training of young vines and the making of wine.

Grapes

Grape production, as an industry, appears to have started around the southern end of the Caspian Sea. From there it spread to other parts of Asia and then to Europe. The Phoenicians carried it to France about 600 B.C., and the Romans planted grapes on the Rhine. At about the same time grape culture was moving around the Mediterranean to North Africa. As the Europeans colonized new lands, the grape was always among the plants taken along. Today it is cultivated on all the continents and islands of the world where climatic conditions are favorable for its production.

Species. One species, *Vitis vinifera* L., supplied all of the grapes that were grown by civilized man for centuries. It is the grape mentioned in the Bible; the grape of the myths and of poets; the grape from which the wines and raisins of world commerce and most of the table grapes are produced. It is the Old World grape, the European grape, and more recently in America the California grape.

Not until eastern North America was colonized was there need for other species. Here the insect phylloxera, *Dactylospheara vitifoliae* Shimer, and several cryptogamic diseases destroyed the vines of *Vitis vinifera.* Fortunately, North America was blessed with many native species of *Vitis.* The species of the Midwest and East, which had lived with the phylloxera and diseases, were resistant to their attack. With the failure of their vinifera vines, the American colonists turned to the native *Vitis* species for grapes. Selections of *Vitis Labrusca* L., or hybrids of it with vinifera and other American species, formed the basis of a new and different grape industry in that part of the United States. These are true grapes, but they differ greatly from vinifera in both morphology and in the flavor of their fruit. Many of these are so-called "slip skins" and have a pronounced aromatic or "foxy" flavor.

In the southern part of the United States east of Texas, varieties of *Vitis rotundifolia* Michaux are cultivated. These are muscadines, not true grapes. The berries are borne singly or in very small clusters, mature irregularly, and drop when ripe. Nevertheless, they are important, since they are very hardy under hot and humid conditions.

Not content with the best grapes in the world and in the interest of science, Europeans introduced the American grapes when these became available. With these plants, unbeknown at the time, they unwittingly took the insect phylloxera and the diseases downy mildew, *Plasmopara viticola* Berk. and Curt., and black rot, *Guignarda Bidwellii* Ellis, to Europe. In the course of little more than two decades following its introduction into France, phylloxera destroyed most of their vineyards. To reconstitute these vineyards, French viticulturists came to America in search of rootstocks that were resistant to this organism. They were successful, and soon the decadent vineyards of Europe flourished again, but on rootstocks of American species or hybrids. Among the rootstocks are selections of *V. rupestris* Scheele, *V. riparia* Michaux, and *V. Champini* Planchon, hybrids of these, and *V. cinerea* Engelman, *V. Berlandieri* P., *V. Candicans* Eng., *V. Solonis* Berol. and Planch. and *V. Monticola* Buc., or hybrids of vinifera varieties with certain of the foregoing species.

Along with their efforts to control phylloxera Europeans attempted to produce vines that were also resistant to various diseases by hybridizing *Vitis vinifera* varieties with American species, such as *V. aestivales* Michaux, *V. riparia*, *V. Lincecumii* Buckley and *V. rupestris*. These hybrid varieties are neither "slip skins" nor foxy in flavor. They are the so-called "producteurs directs" which are grown to some extent in certain parts of Europe because of their resistance to fungus diseases.

Kinds of Grapes. On the basis of use, grapes are grouped as follows: (*a*) wine grapes, (*b*) raisin grapes, (*c*) table grapes, (*d*) sweet juice grapes, and (*e*) canning grapes. The mature fruit of all named grape varieties—about 8,000—will ferment into a kind of wine when it is crushed, and most of them can be dried or eaten fresh. Only a limited number of varieties, however, produce standard or higher quality wines. The raisins of commerce are produced mainly from three varieties, less than a dozen varieties are grown extensively as table grapes, the bulk of the sweet juice produced in America is of one variety, and only one variety is used for canning.

A wine grape may be defined as a variety known to be capable of producing an acceptable wine in some locality. Table (or dry) wines require grapes of high acidity and moderate sugar content, while dessert (or sweet) wines are more palatable if the grapes are high in sugar and moderately low in acidity. In addition to the constituent balances just stated, high quality wines, which are outstanding in bouquet, flavor and general balance, require that the grapes utilized in their production possess special characteristics, such as those of the White Riesling, Semillon, Cabernet Sauvignon, Tinta Madeira and similar varieties when they are grown under favorable climatic conditions.

Raisin grapes are grapes that produce an acceptable dried product. Raisins, therefore, are dried grapes; yet different varieties and different methods of drying yield very unlike products. To be a good variety for the production of raisins, the dried product must possess: (*a*) a soft texture, (*b*) little tendency to become sticky, (*c*) seedlessness, (*d*) a marked, pleasing flavor, and (*e*) large or very small size. Only the products of the Thompson Seedless, Muscat of Alexandria and Black Corinth meet most of these requirements.

Grapes used fresh, either for food or for decoration, are generally called "table grapes." They must be attractive in appearance and pleasing to the palate. Large size, brilliant color and unusual form are generally appreciated. Where these grapes must be shipped long distances to reach the markets, or when they are to be stored for a considerable period, firmness of pulp, toughness of skin and adherence to the pedicel become very important. These qualities are possessed in marked degree by the table varieties, such as the Flame Tokay, Emperor, Malaga, Red Malaga (Molinera), Almeria (Ohanez) and Ribier (Alphonse Lavallee), all of which are grown in California, South Africa, Australia, Argentina and elsewhere. The Thompson Seedless (Sultanina) owes its popularity mainly to its seedlessness.

Sweet juice grapes are those varieties of which the juice produces an acceptable beverage when it is preserved by pasteurization or germproof filtration. The juice must retain the natural fresh-grape flavor. In America pasteurization alone has been employed to preserve grape juice. Most vinifera varieties, including the strong-flavored Muscats, when pasteurized by the usual methods,

THE PRINCIPAL GRAPE-PRODUCING COUNTRIES OF THE WORLD, WITH THE APPROXIMATE ACREAGE AND AVERAGE ANNUAL PRODUCTION OF WINES, TABLE GRAPES AND RAISINS FOR EACH DURING THE PAST FIVE YEARS

	Area in grapes (thousands of acres)	*Wines (millions of gallons)*	*Table grapes (thousands of tons)*	*Raisins (thousands of tons)*
Austria	83	22		
Bulgaria	379	53	70	
Czechoslovakia	43	14		
France	3,340	895	145	
Germany	153	45		
Greece	548	68	75	95*
Hungary	598	125	20	
Italy	3,160	880	140	10
Portugal	860	260		
Roumania	520	220	350	
Spain	3,380	495	190	11
Switzerland	32	20	2	
Yugoslavia	550	125		
Cyprus	133	2	15	4
Syria	121	2	10	1
Turkey	1,090	15*	80	60
U. S. S. R.†	870	130	275	30
Algeria	840	490	18	
Tunisia	67	14	2	
Union of South Africa	97	50		11
Argentina	430	210	250	5
Brazil	84	20		
Chile	247	80		2
Australia	128	21	15	82
United States—total	670	120	630	260
United States—California	490	110	500	260

Sources of data: International Yearbook of Agriculture and Bulletin Office International du Vin Nos. 201 and 202.

* On basis of prewar records and minor changes in acreage figures appear low.

† In view of new planting and acreage shifts during World War II, all figures appear low.

lose their fresh flavor and acquire an unpleasant cooked taste. The strong-flavored American varieties, particularly the Concord, are less affected by pasteurization. This fact largely accounts for the general use of the Concord for juice in the United States—of course, some people like these flavors. In central Europe a thriving industry was developed prior to World War II using close filtration for sterilization. There the good vinifera varieties, such as the White Riesling and Chasselas doré, that had won renown for wine production, were used for juice.

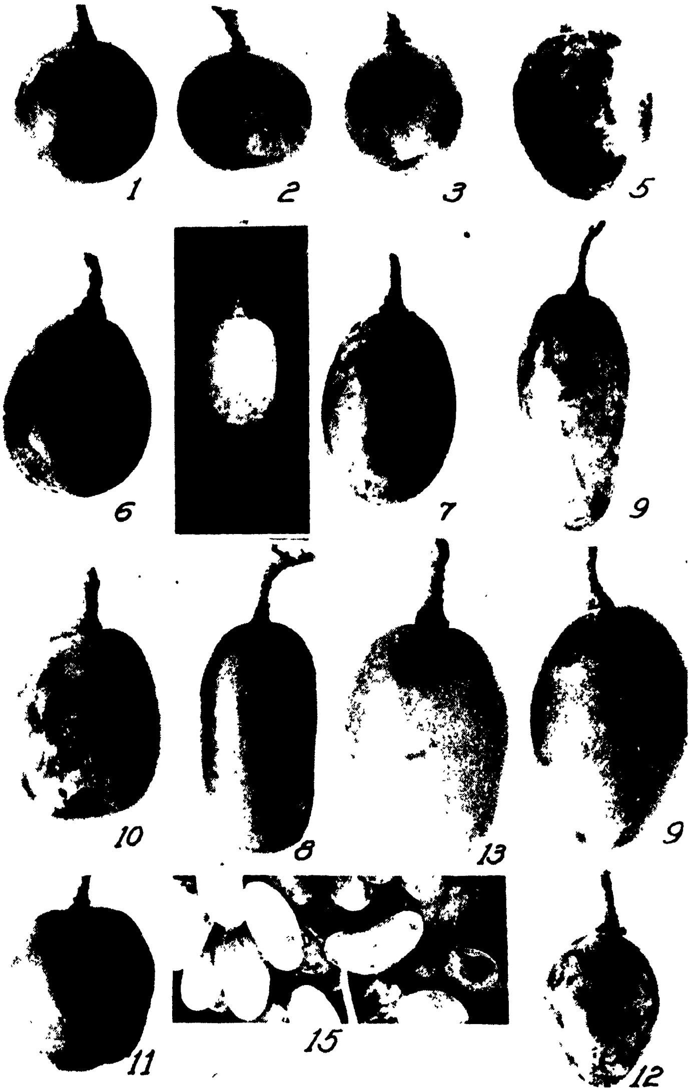

FIG. 1. Grape berry shapes: 1, spherical; 2, oblate; 3, ellipsoidal; 4, cylindrical; 5, ovoid; 6, obovoid; 7, ellipsoidal elongated; 8, cylindroidal elongated; 9, ovoid elongated; 10, obovoid elongated; 11, ovoid truncated; 12, ovoid pointed; 13, fusiform; 15, falcoid (*Hilgardia* **11** (6)).

Grapes are canned largely in combination with other fruits in the production of fruit salad and fruit cocktail. Only seedless sorts are used, usually the Thompson Seedless.

Extent and Distribution of Industry. The principal grape-producing countries of the world, together with the acreage planted to grapes in each, with approximate yields, are listed in the accompanying table.

Owing to the ravages of war, the production in Europe suffered severely during the past decade. Nevertheless, the first ten countries in the order of importance in the production of wine are: France, Italy, Spain, Algeria, Portugal, Roumania, Argentine, Russia, Yugoslavia and Hungary. The United States produces less than 3 per cent of the wines of the world.

The production of table grapes and raisins was increased during the war years. The United States, or more correctly California, has retained first place in the production of both table grapes and raisins. Statistics indicate that roughly 20 per cent of the world's table grapes and 40 per cent of the world's raisins are produced in California.

Climate. Vinifera grapes require long, warm to hot, dry summers and cool winters for their best development. Humid summers favor the development of diseases that attack the fruit, while severe winter conditions (0° F or below) will destroy the vine if it is not protected. Spring frosts after the vines start growth kill the shoots and clusters. Rain during winter to supply soil moisture is desirable, but summer rains make the control of diseases more difficult Rains of considerable duration during the ripening and harvest periods may cause rotting of the fruit. Where raisins are to be produced by natural sundrying, as is the custom in California, a month of clear, warm, rainless weather after the grapes are mature is essential.

Varieties possessing the characteristics of *Vitis Labrusca* will withstand humid summers and colder winters better than those of vinifera. In fact, they may do better where summer rains of short duration are the rule. Varieties of *Vitis rotundifolia* thrive in very warm, humid regions of the southeastern states of the United States.

The limitation of grape production to the temperate zone is due to climate. As climate limits grape-growing to a broad zone, so it also limits the highest development of individual varieties to localized areas within this zone. For example, the Flame Tokay, a table grape, attains its most acceptable development in California in the warm, dry, ten-square-mile area at Lodi, and the Emperor, table grape, is restricted to a hot, dry district in eastern Tulare and Fresno counties; while the combination of the particular climate of certain regions of Europe with the qualities of White Riesling, the Pinot noir, Cabernet Sauvignon, and Chardonnay have made possible some of the greatest table wines of the world.

Table wines are better when the suitable varieties are grown in cool regions. Under relatively cool conditions ripening proceeds slowly. This is favorable for the production of high quality, since it fosters the retention of a high degree of acidity, low pH and the development of good color. With most table-wine varieties, these conditions bring the aroma and flavoring constituents of grapes and the precursors of the bouquet and flavoring substances of the wines to the highest degree of perfection in the mature fruit.

An abundance of heat is ideal for production of the grape varieties from which dessert wines such as port, Muscatel and sherry are derived. Large summations of heat, especially just before and during ripening, favor a high ratio of sugar to acid in the mature fruit, which, with the development of the other constituents of the fruit under such conditions, make for smoothness and mellowness in the aged product. The effect of the heat on the aroma and flavor is less objectionable than with table wines.

Temperature is by far the most important factor of climate. In addition to its effects indicated above, temperature governs the time elapsing from full bloom to a given degree of maturity. For example, 2,000° days (a degree-day as used here is 1° above 50° F for 24 hours) will bring the fruit of Thompson Seedless from full bloom to 18° Balling (per cent total soluble solids). Other varieties require more or less heat, depending on whether or not they are early or late maturing. Although this total summation of heat may be used to indicate degree of maturity, it does not indicate palatability. This is influenced more by the summation of heat during the ripening period. With cool weather during this period, the fruit will be higher in acid and taste sour, while with hot weather it will be lower in acid and taste sweet.

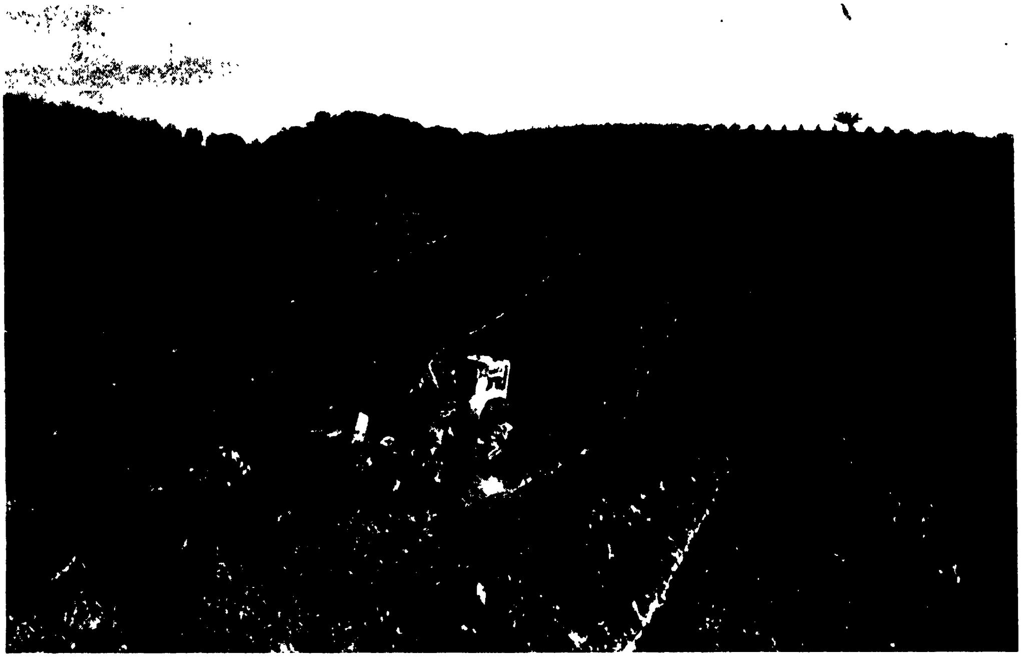

FIG. 2. Vineyard of the coastal area of California (for vineyards of the interior valleys of California see Fig. 8). (*Courtesy of the Wine Institute.*)

Vineyard Soils. Grapes are adapted to a wide range of soils. Grape growers often express a preference for certain soil types, yet when a survey is made of soils used for grapes in the many different localities, it is found that grapes grow on soils ranging from blow sands to clay loams, from shallow to very deep soils, highly calcareous to noncalcareous soils, and from low to high fertility. The extremes in all these variations are less desirable, and poorly drained soils or soils containing excess salts are to be avoided. The deeper and more fertile soils produce the highest tonnages; they are preferred for raisins, common wine grapes and some table grapes. *A priori* information would appear to indicate that certain of the better wine grapes and certain table-grape varieties attain a higher quality when grown on soils of limited fertility and depth.

Establishing the Vineyard. Commercial grape varieties are propagated asexually. This is accomplished by utilizing cuttings or making grafts which are grown for one year in the nursery. The cuttings may be of fruiting varieties or of rootstocks. The grafts consist of a segment of a stem of a fruiting variety placed on a rootstock cutting. In Europe grafts are regularly used to establish vineyards where root-destroying organisms are present. In California grafts and rooted rootstock cuttings are employed. The latter are field budded to the desired fruiting variety in late summer after they are planted in the vineyard.

For convenience in planting, the roots of the rooted vines or grafts are shortened to three or four inches. These are planted at the same depth they stood in the nursery. The union of grafted or budded vines must be above the soil so that there is no scion root production. Planting distances vary widely in the different countries of the world. In Europe the distances range from 3 × 3 feet to 4 × 7 feet, while in California, where cultivation is largely mechanized, the widest spacing is employed; the vines are planted 7 × 7, 8 × 8 and 8 × 10 in the coastal areas, 10 × 10 and 8 × 12 feet in the interior valleys. Intermediate planting distances are used in Australia, South Africa and South America.

Training consists in the development of a vine of desirable form. It is accomplished by pruning and the tying of the young vine and its growth to the support. Vinifera varieties are trained to two general forms, namely, headed and cordon vines (Fig. 3). In the former there is a straight, vertical trunk or stem of the desired height, with arms radiating out from its top to form the head, while with the latter the trunk is much elongated, either vertically or horizontally. The most widely used cordon is the bilateral, in which the trunk rises vertically to the desired height where it is divided into the two branches which extend horizontally in opposite directions along the row. Arms arise on the upper side of the horizontal parts of the trunk. Head training is universal for wine and raisin grapes and some table varieties. The bilateral cordon is useful for certain large-clustered table grapes, especially Ribier and Red Malaga. These are the commercial systems, but minor variations from them occur in some producing areas, and it must be remembered that the vine is readily trained to walls, pergolas, and arbors.

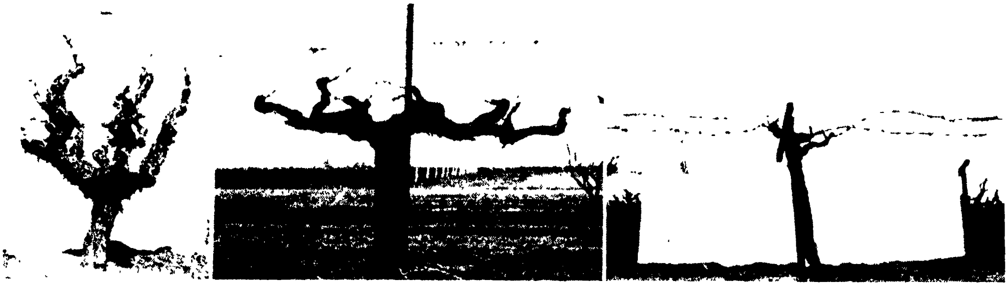

FIG. 3. Systems of training and pruning: (*Left*) Head-training with spur pruning. (*Center*) Cordon-training with spur pruning. (*Right*) Head-training with cane (or long) pruning.

The common supports for all head-trained, spur-pruned vines are stakes, while the cordon-trained, spur-pruned and head-trained, cane-pruned vines are usually supported with trellises. The most generally used trellis has two wires, the bottom wire being at 34 and the top wire at 48 inches above the ground. The stakes and wire supports are usually 2 x 2 inch split, durable wood, such as redwood in California, of desirable length: four, six or eight feet, according to the variety and the country.

Pruning. Pruning is the most important single vineyard operation. It is usually the sole means of regulating crop with wine and raisin varieties, and thus it largely determines not only the quality of the fruit but also the quality of the wood for the next year. From 90 to 95 per cent or more of the year's growth of shoots or canes is removed at the annual pruning. At pruning, spurs or fruit canes, or both, are retained. Spurs are used for the varieties of which the basal buds, near the point of origin of the canes, are fruitful, while fruit canes are necessary where the buds near the basal end of the cane are unfruitful, and with varieties that produce very small clusters in which many clusters are required to produce a full crop. Spurs of one, two, three or four buds in length are used according to the fruiting habit of the variety and the size of the individual cane from which the spur is retained. Likewise, canes vary in length from eight to 12 or 15 buds. The number of spurs or canes retained on a vine should vary with its size and the vigor of the year's growth. In cane pruning a renewal spur of 2 buds is retained for each fruit cane for the production of fruiting wood for the next year and to aid in maintaining the form of the vine. The canes are removed after they have produced a crop. Variations from the above procedure are encountered, but they are largely adaptations to local conditions and not in principle.

The grape starts growth late in spring, not until the mean daily temperature reaches approximately 50° F. Growth is rapid, reaching a peak in early summer; then it slows down so that little further shoot elongation occurs after the fruit begins to ripen. The leaves, however, continue to function until the end of the season. Fruit-bud differentiation begins with the accumulation of carbohydrates in the shoots soon after length growth slows down in summer. The cluster primordia develop to the growing points for the individual flowers by leaf fall. Thus, the number of flowers to be produced and the shape of the clusters are largely determined in the year prior to that in which the fruit is produced. The parts of the flowers develop in the spring after growth starts. Grapes bloom six to eight weeks after leafing out, depending on seasonal conditions.

Set of the Berries. In the normal setting of the fruit of the grape, pollination is followed by fertilization and this in turn by seed development. Along with this type of fruit setting there are a considerable number of varieties in which part or most of the normal mechanism of fruit setting fails to function. As a result, there is wide variation in berry size, berry shape and uniformity of size and shape which is correlated with the type of fruit setting of the variety. Four types of fruiting or fruit setting will be mentioned. Although these variations are continuous from one type to the other, the set of fruit within an individual variety is relatively constant.

The most common type of setting is that in which normal seed development occurs. In such varieties each carpel has one, two or more seeds, and the berries are relatively uniform in size and shape. They are round, oval or fusiform, according to the variety. In other varieties only one or two seeds develop to a berry. With much elongated berries, the presence of a single or two adjacent seeds may cause the berries to be facoid in shape (see 15, Fig. 1).

In a second type most of the seeds produced are empty. Empty seeds result from embryo abortion after the seed is well advanced in its development. Some varieties produce less than three per cent of viable seeds. As a rule, the berries of such varieties are non-uniform in both size and shape; that is, the variation resulting from the stimulus of fertilization and the different stages of development attained by the embryo prior to aborting is marked.

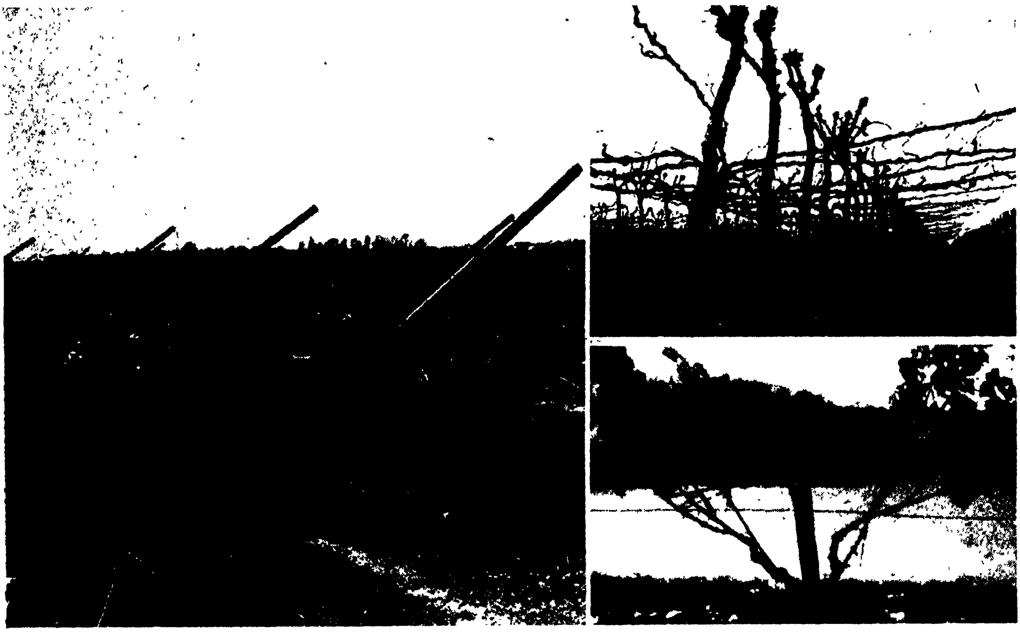

Fig. 4. Supports for vines: (*Left*) Sloping top, four-wire trellis, California. (*Upper right*) Trees for vine supports, Italy. (*Lower right*) One-wire trellis, France. (See Figs. 2 and 5 for simple stake supports.)

The other two types result in seedless fruit. There are two different types of seedlessness among commercial grape varieties. In the one type fertilization takes place, but abortion occurs sufficiently early so that only rudiments of seeds are present. These are thin-walled or often hardly more than enlargements of the vascular strands. This type of fruit setting is common to a number of important varieties. The best known is the Thompson Seedless which produces two thirds of the world's raisins and is used extensively as a table grape in America.

In still another type the fruit setting is by stimulative parthenocarpy. In this type the berries are very small and round, with no trace of seeds. Seedlessness and small size, however, have been important factors in making the Black Corinth of great commercial importance. The variety supplies the Zante or dried currants of commerce.

Thinning Table Grapes. Not all varieties of grapes set equally well. Some varieties set clusters that are too compact; the clusters of others are well filled; those of others are loose to the point of being straggly; and still others set shot (parthenocarpic) berries along with the normal berries.

As an aid in correcting the objectionable features of the setting of certain varieties of table grapes, several methods of fruit thinning have been developed. When an overabundance of berries makes the clusters too compact or when overlarge cluster parts interfere with proper coloring and maturing, berry thinning will improve quality. As used in California, berry thinning consists in removing parts of clusters, usually by cutting the rachis, to leave only the desired number of berries, while in other areas individual berries are removed. When the thinning is done soon after the set of the berries, a marked increase in berry size is usually obtained.

In another method flower clusters are removed soon after they emerge, which with no removal of leaves improves the carbohydrate nutrition of those retained. As a result, a better set of normal berries may be secured. Flower-cluster thinning is useful on varieties that have loose or straggly clusters, or which tend to set shot berries with the usual pruning. The increase in the set of normal berries appears to affect sufficiently the nutrition of the flowers that are not fertilized to reduce the setting of shot berries. For best results the vines should be pruned to retain more buds and then thinned as soon as possible after the flower clusters appear.

A third method, cluster thinning, consists in the removal of entire clusters soon after the berries have set. By leav-

FIG. 5. Tractor-drawn disk with two Molley plows attached at opposite sides to back of disk, and with two Kirpy plows, one right and one left hand, attached by chains to back corners of disk. This combination of implements with three men effectively cultivates 20 acres of vineyard per day. (*Cal. Agr. Exp. Sta. Circ.* 116.)

ing enough fruiting wood at pruning to produce a full crop in all years and then reducing the overload in years of good set by cluster thinning, larger crops of high-quality fruit can be produced every year. By improving the nutrition of the fruit that is retained, cluster thinning enhances the size and color of the berries and tends to advance maturity.

Girdling. This operation, which is also called "ringing", consists in removing a complete ring of bark, $\frac{3}{16}$ to $\frac{1}{4}$ inch wide, from the trunk or a cane below the fruit which it is intended to affect. As a result, carbohydrates can not move downward, through the phloem, and an accumulation occurs above the girdle.

When the girdle is open and effective during bloom, it increases the set of seedless berries; when it is open during the period of rapid growth of seedless berries, it increases the size of berry; and when it is open during the early part of the ripening period of seeded varieties, the coloring and ripening may be accelerated. Girdling is a regular operation for improving the set of Black Corinth wherever it is grown and for increasing the size of berry and firmness of Thompson Seedless and improving the coloring of Ribier and Red Malaga in California.

Cultivation. In unirrigated vineyards the only water available to the vines is the underground water. In areas of rainless summers, as in California, or where periods of drought are of common occurrence, the weeds are destroyed before they rob the vines of appreciable amounts of soil moisture. A winter covercrop or growth of native plants is usually encouraged. On rolling soils and hillsides this winter cover is of great value in preventing erosion. The winter cover is destroyed at the end of the rainy season or at the spring cleanup (Fig. 5). Cultivation should be repeated only often enough to destroy or prevent further weed growth. Cultivation conserves soil moisture only by eliminating weeds and not by virtue of loosening or pulverizing the soil. In the absence of perennial noxious weeds, it is discontinued as soon as the surface soil becomes too dry for seed germination. Shallow cultivation is favored in most vineyard areas.

In irrigated vineyards the matter of weed competition is of less importance. Such vineyards are usually cleaned up in spring and kept free of weeds during the period of rapid vine growth in order to eliminate weed competition for soil nutrients. When ample soil moisture is available, weed growth after midsummer is controlled only to prevent undue interference with the various vineyard operations. For example, in many table-grape vineyards of California that are free of noxious weeds, the native grasses are permitted to grow. It appears that the readily available supply of certain elements is utilized by the grass and vine to such an extent that vine growth is checked, and, as a result, maturing is advanced and the grapes may be of a firmer texture, have a tougher skin, have better matured stems, and be more brilliant in color.

Irrigation. Vinifera grapes do best in long, warm-to-hot, dry summers; however, where the rainfall is insufficient to meet the water requirements of the vine, the deficiency in soil moisture must be made up by irrigation. In the absence of sufficient rain, the soil is wetted as deep as the roots penetrate during the late fall, winter or early spring. After growth starts, the vines are allowed to almost exhaust the available water in the soil area containing most of the roots, then water is applied to rewet the soil. This practice should be repeated as required until the grapes are nearly ripe; the amount and frequency of the applications of water being determined by the texture and depth of the soil, climatic conditions, type of grapes grown and cultural methods. In very hot regions or with early-maturing sorts, one or more irrigations may be required after harvest to maintain vine growth so that the wood will mature normally.

Insects and Diseases. The grapevine and its fruit are seriously attacked by a number of insects and diseases. In the arid countries or regions there are fewer pests. In California and other arid rigions the principal insects attacking the vine are the phylloxera, *Dactylosphaera vitifoliae* Shimer, a root louse, and the root knot nematode, *Heterodera marioni* Cornu, which are combated by using resistant rootstocks. The grape leafhopper, *Erythroneura elegantula* Osb., which is controlled with DDT; the grape root worm, *Adoxus obscurus* Li.; the grape leaf roller, *Desmia funeralis* Hübner; and the red spiders, *Tetranychus pacificus* McG., which can apparently be controlled by some of the new organic phosphate insecticides either as dusts or sprays, are also important. In more humid regions there are in addition to the above the berry moths, *Polychrosis botrana* Schiff and *Clysia ambiguella* Hübner, and various beetles and caterpillars which may be controlled with arsenicals.

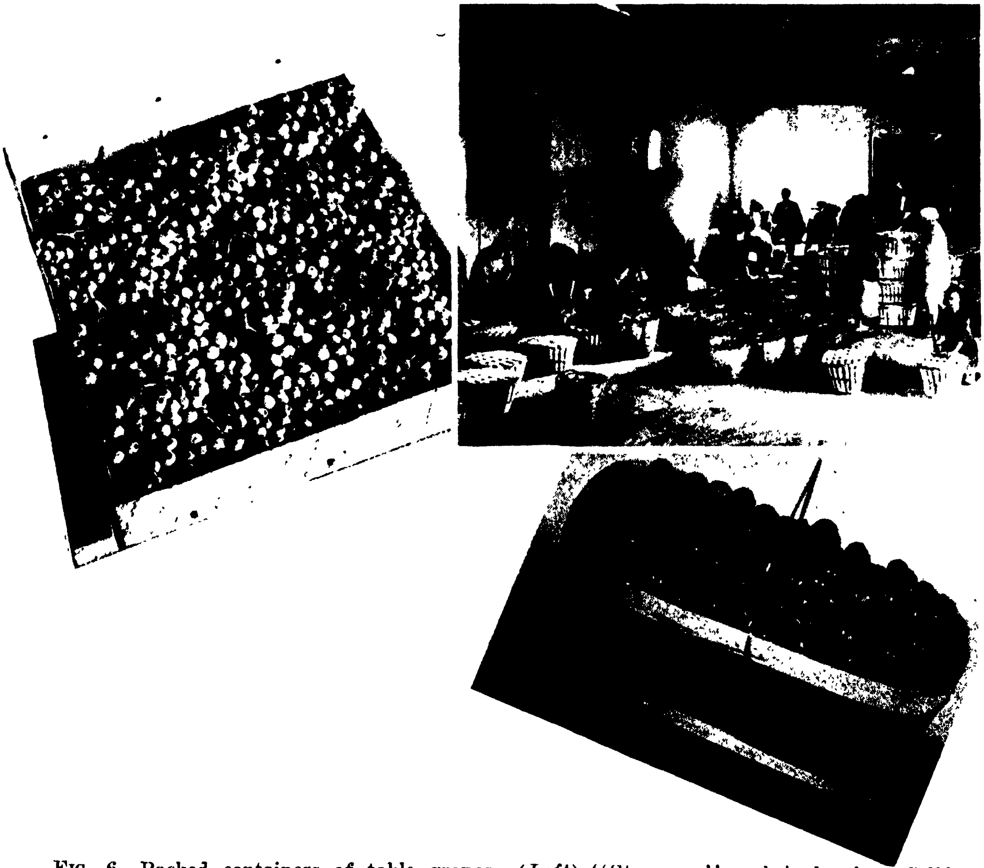

FIG. 6. Packed containers of table grapes: (*Left*) "Stems up" pack in lug box, California. (*Upper right*) Large slat baskets, Algeria. (*Lower right*) Climax basket, eastern United States. (*Last from U. S. Dept. Agr., Farm. Bull. 1558.*)

Diseases affecting the grape under arid conditions are powdery mildew, *Uncinula necatar* Schw., prevented by dusting elemental sulfur on all green parts of the vine; black knot, *Phytomonas tumefaciens* Smith and Towne; Pierce's disease (in California), a virus, control unknown; and black measles, cause unknown but controlled by sodium arsenite spray while the vines are completely dormant. Under humid conditions the grape is also attacked by black rot, *Guignarda Bidwelli* Ellis; anthracnose, *Gloeosporium ampelophagum* Pass.; downy mildew, *Plasmopara viticola* B. and C., which are controlled with Bordeaux sprays; *Cryptosporella viticola* Reddick, which is controlled by sodium arsenite; and numerous minor diseases.

Harvesting. A grape is ripe when it has reached the stage best suited for the use to which it is to be put. The ripe stage is the condition that results when the changes in the several components that make up quality have proceeded to a point where their combined effect on the quality of a given variety is the nearest possible approach to an ideal for a given purpose. The ripe stage is not absolute nor does it represent the end product in the changes that are proceeding in the berries. For example, for

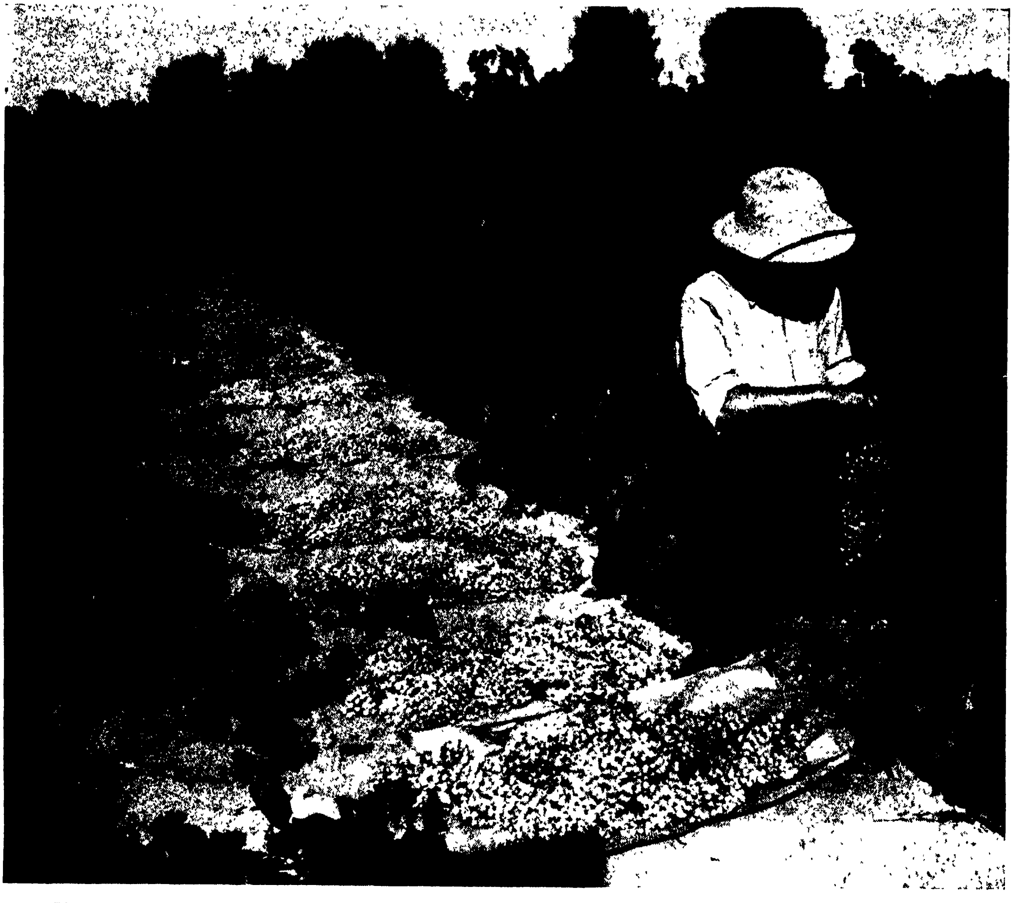

FIG. 7. Picking Thompson Seedless grapes directly onto trays for sun drying between the vine rows.

one purpose a grape of moderate sugar and relatively high acid content may be best, while for another purpose high sugar content and low acidity may be most desirable.

Table grapes are harvested when they are sufficiently mature to be attractive and palatable. Above the minimum sugar content for the variety the degree of satisfaction with which grapes may be eaten depends on the ratio of sugar to acid.

The containers in which table grapes are moved to market and the methods of packing the fruit in the containers vary greatly from country to country (Fig. 6). The least handling consistent with thorough trimming, to remove injured berries, and with efficient packing is imperative. The sooner the grapes are cooled after being removed from the vine, the better will be their quality when they reach the market. Deterioration is very rapid at high temperatures.

When grapes are to be shipped long distances or held in storage (at 31° F) for prolonged periods, it has been found advisable to supplement the low temperature by treating the grapes with 15 to 20 parts per million of sulfur dioxide which reduces their deterioration markedly. The benefits of treatment with sulfur dioxide are: suppression of the growth of molds and other decay-causing organisms, reduction in the respiration of the fruit and retention of the green coloring in the stems. In the shipment of grapes the best method of applying the sulfur dioxide is by displacing the air of the standard refrigerator car with sulfur dioxide diluted with air to a concentration of approximately 1 per cent by volume. Immediately after the treatment the ventilators and doors of the car are closed, and the grapes absorb the sulfur dioxide. Grapes in cold storage are treated at seven- and ten-day intervals by releasing sulfur dioxide into the air (about ¼ per cent) as it enters the storage room. After 20 to 25 minutes the air with sulfur dioxide is blown out of the storage room.

When raisins are made by the natural sun-drying process, as in California, the riper the grapes the better the raisins and the higher the yield. Thus, the grapes are left on the vines as long as possible and still having a reasonable safe period for drying. The grapes are picked from the vines and spread evenly

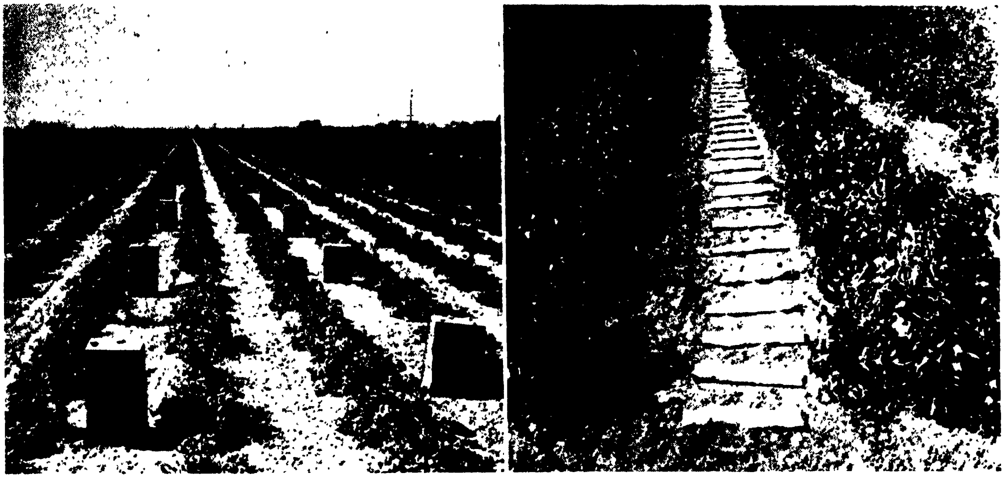

FIG. 8. Finishing the drying of raisins: (*Left*) Stacked wooden trays. (*Right*) Rolled paper trays.

on wooden or paper trays without pretreatment of any kind (Fig. 7). When the berries on the upper side of the clusters have shriveled and turned brown, the grapes are turned upside down onto another tray. In sun drying the slow oxidation that proceeds in the berries is instrumental in the development of the typical raisin flavor. Wooden trays are stacked and paper trays rolled when the raisins are three fourths dry (Fig. 8). In most of the other raisin-producing countries the drying weather is less favorable, and the grapes are pretreated with or dipped into weak caustic or carbonate solutions with or without emulsified olive oil to hasten drying and to produce a lighter colored product. The dips vary in both composition and concentration, but their function is to render the skins of the grapes more permeable, either by checking or by removing the bloom, or both. A limited tonnage of grapes is dehydrated. Grapes to be dehydrated are usually dipped, to produce small checks or cracks in their skin which facilitate water loss, and treated with sulfur dioxide to produce a translucent, golden-colored product. Dehydrated grapes do not possess a "raisin" flavor.

The time for picking wine grapes is influenced by the kind of wine to be made. Grapes for table wines, except for the natural sweet, should be of high acidity and moderate sugar content. Such grapes are usually harvested after they test 18° Balling but before they reach 23°. For dessert wines the grapes should be high in sugar and of moderate acidity. Grapes for sweet dessert wines are allowed to attain as high a sugar content as is possible without raisining—usually 24° Balling or more.

Wines

Wine is the beverage resulting from the partial or complete fermentation of the juice of sound, ripe grapes under controlled conditions.

Man, no doubt, ate the fruit of the vine long before he became acquainted with fermentation and its possibilities. Yet, the records of the early spread in grape production show that it was largely of varieties adapted for wine and not for eating fresh. This would indicate that man has long been familiar with wine.

Kinds of Wine. The great variety of grapes used, differences in the environmental conditions under which the grapes are grown, differences in the degree of completeness of the fermentation, and differences in the cellar treatment has resulted in the production of many kinds of wines in various parts of the world.

Despite the large number of individual kinds, wines may be grouped into two classes, namely, those that derive their alcohol entirely from their own fermentation and those to which grape spirits (alcohol) are added in addition to that derived from their own fermentation.

The wines of the first group may be dry or sweet, white or red, still or sparkling. These wines have been called "dry wines", "natural wines", "light wines", *etc.*, but none of these terms covers accurately all of the kinds included—some of them are quite sweet and others are decidedly heavy (alcoholic). All of these wines, however, are intended for consumption primarily with food; hence it appears that they may be more correctly termed "table wines". The wines of European countries are predominantly of this group—90 per cent or more.

The wines of the second group again may be sweet or dry, white or red, but they are always still. These wines may best be called "dessert" and "appetizer" wines, since this again indicates their most common use. More than two thirds of the wine produced in the United States belongs to this group.

Beyond these large groups, wines are

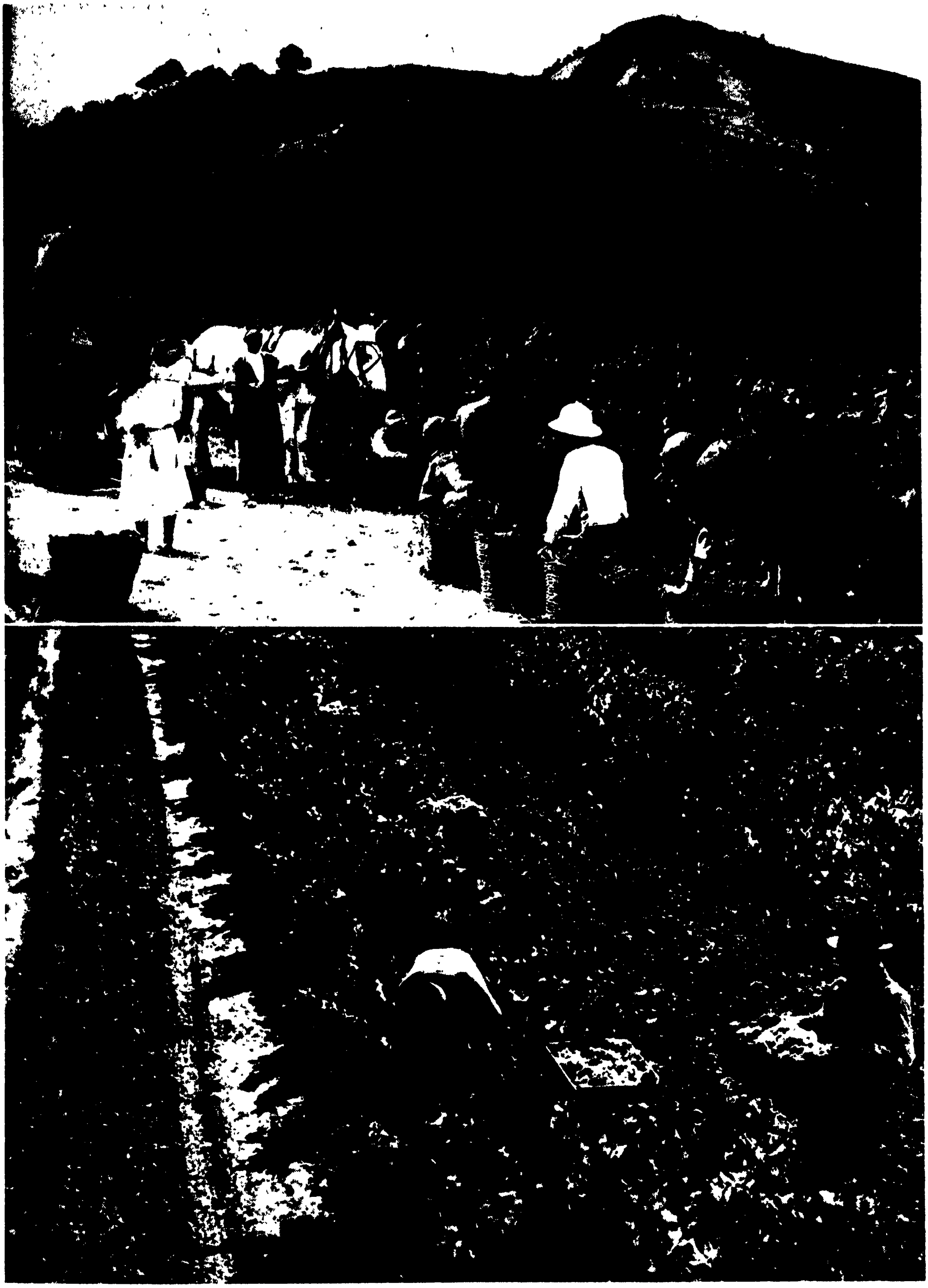

FIG. 9. Picking wine grapes: (*Upper*) In Algeria. (*Lower*) In California.

segregated according to the country of origin and the type. Wines are of a single type when their general and special characteristics show a pronounced similarity. In the case of "table wines", for example, if the term "type" is to have significance, a given type may include only wines of a single variety of pronounced character, a principal variety of pronounced character and several minor supplementary varieties, or several varieties of distinct character that are produced under special environmental conditions. In each case the vinification procedure must be such that will bring the potential qualities of the mature grapes to their full development in the aged wine. Most "dessert" and "appetizer" wine types, on the contrary, are usually blends within and between years, but again they must be of a limited producing area and of standardized vinification practice. Some varietal wines, such as the Cabernets and Muscatels, because of their very pronounced aroma and flavor, may be produced under conditions that vary considerably and still retain their type identity.

Wine Types. Each of the countries growing wines has one or more types. Most of these are primarily of local interest; some, however, have gained recognition beyond the borders of the producing areas, and others have won world renown. Only a few types will be mentioned for purposes of illustration.

Recognized white table wine types are: Riesling of Germany; Tokai of Hungary; Chablis, Champagne, Sauternes and White Burgundy of France; and Chardonnay, Johannisberg Riesling, Sauvignon blanc, Semillon of California.

Red table wines of general interest are: Burgundy and Claret of France; Chianti and Barolo of Italy; Cabernet, Pinot noir and Zinfandel of California.

Dessert wine types are less numerous. The better known are: port, angelica, muscatel and the sweet sherries.

The appetizer wines are the dry sherries and vermouth.

Fermentation. Transformation of the sugars in the juice of grapes to alcohol and carbon dioxide by yeasts under favorable conditions is called "fermentation". It is brought about by enzymes produced by yeasts. Other organisms, such as molds and bacteria, may also bring about the fermentation of sugars, but they impart undesirable flavors to the product and are incapable of producing a high percentage of alcohol. Yeasts, too, vary in their ability to ferment; in the efficiency of the fermentation; and in the character, quantity and and type of the by-products produced. The wine yeasts, *Saccharomyces ellipsoideus* strains, ferment the must or juice free of sugar and produce a desirable vinous flavor.

The use of selected yeasts is a regular practice in many wine-producing areas. This is particularly true when weather conditions during the harvest are unfavorable and when sulfur dioxide is employed to check the activities of undesirable organisms. The use of a pure culture of yeast (1 to 3 per cent of the total) together with sulfur dioxide (50 to 100 p.p.m.) results in a fermentation that begins promptly, proceeds vigorously and goes to completion. Although some strains of wine yeast may have some inherent flavor-producing capacity, the quality and character of the wine is determined largely by the grape variety used, its delicacy and richness being governed by the environment in which the grapes are grown.

In the fermentation of grape must, the principal products are alcohol and carbon dioxide. The quantity of these as well as the kind and concentration of the by-products will vary with the strain of yeast used and with the composition, temperature and extent of the aeration of the must. The overall equation for the fermentation of grape must is as follows:

$$\underset{\substack{\text{dextrose}\\ \text{or}\\ \text{levulose}}}{C_6H_{12}O_6} \rightarrow \underset{\substack{\text{ethyl}\\ \text{alcohol}}}{2C_2H_5OH} + \underset{\substack{\text{carbon}\\ \text{dioxide}\\ \text{gas}}}{2CO_2}$$

The process, however, is much more complex than this equation indicates. The fermentation of grape sugars proceeds in a series of well-defined stages, involving the formation of a number of intermediate products and the interaction of several enzyme systems. Acetaldehyde, glycerin, 2,3-butylene glycol, lactic acid and acetic acid are regular products of alcoholic fermentation. Other products, such as succinic acid and higher alcohols, which are produced only in small amount but which may be of considerable importance, arise when there is over-aeration during fermentation or as a result of the action of yeasts on substances other than sugars.

The above equation indicates a theoretical yield of alcohol of 51.1 per cent of the weight of the sugar used. In practice, however, the yield of alcohol approximates only 47 per cent, the remainder of the sugar being used by the yeast for growth and respiration or converted into other products.

In the production of white table wines only the free-run juice is fermented. After crushing, the juice may be permitted to stand on the skins for a time to absorb more of the flavors and aromas of the grape. The juice should be allowed to settle prior to the fermentation. Fermentation at a low temperature is preferable. In the production of red table wines, on the contrary, the fermentation must be on the skins, which are kept punched down or immersed in the liquid to facilitate the extraction of color and aroma. The pigment, an anthocyanin, is in the cells of the skin in all red and most black varieties, and is not released until the semipermeability of the cell walls is destroyed by the alcohol produced in the fermentation. When the color of the fermenting wine is sufficiently dark, the juice is drawn off, and the fermentation completed off the skins. This procedure also fosters the extraction of other substances, particularly tannin. In the production of rosé wines the period of fermentation on the skins is very much reduced, and usually only grapes of moderate color are used. The fermentation of juice alone is carried out in closed containers to utilize the protection of the atmosphere of carbon dioxide over the fermenting mass, provision being made for the escape of carbon dioxide.

With the much restricted period of fermentation of sweet dessert wines, it is common practice to ferment on the skins, except where a very light color is desired. In the latter and in the case of dry sherries the crushed grapes are usually allowed to stand until the pomace rises to the surface; then the free-run juice is withdrawn and fermented separately. To facilitate the extraction of flavors and color from the skins in the production of red dessert wines where the fermentation is interrupted soon after it gets well under way, necessitates the utilization of procedures to retard the rate of fermentation. A reduction in temperature is the most desirable means.

Sparkling wines, such as champagne, are made naturally effervescent by a second fermentation in the bottle (or in a closed container). The amount of sugar required to produce the desired pressure and a culture of champagne yeast are added to a suitable table wine that has been brought through the normal fermentation and clarification. It is then bottled in special champagne (strong) bottles which are corked with special corks that are held in place with steel clamps. Since the carbon dioxide cannot escape, pressure is generated during the fermentation of the added sugar. The pressure (usually about six atmospheres) is governed by the amount of sugar present. The sediment produced in the bottles during the fermentation must be removed. This is accomplished by working it onto the cork, the bottle being inverted (Fig. 10), and then removing the cork and spilling enough wine to sweep out the sediment. The bottles are then refilled with the same wine from another bottle or after adding a small quantity of a special sweetened dosage, and finally they are recorked and the cork tied in place with wire. The sugar in this final dosage does not ferment because of the carbon dioxide content, the pressure and the low level of the yeast nutrients.

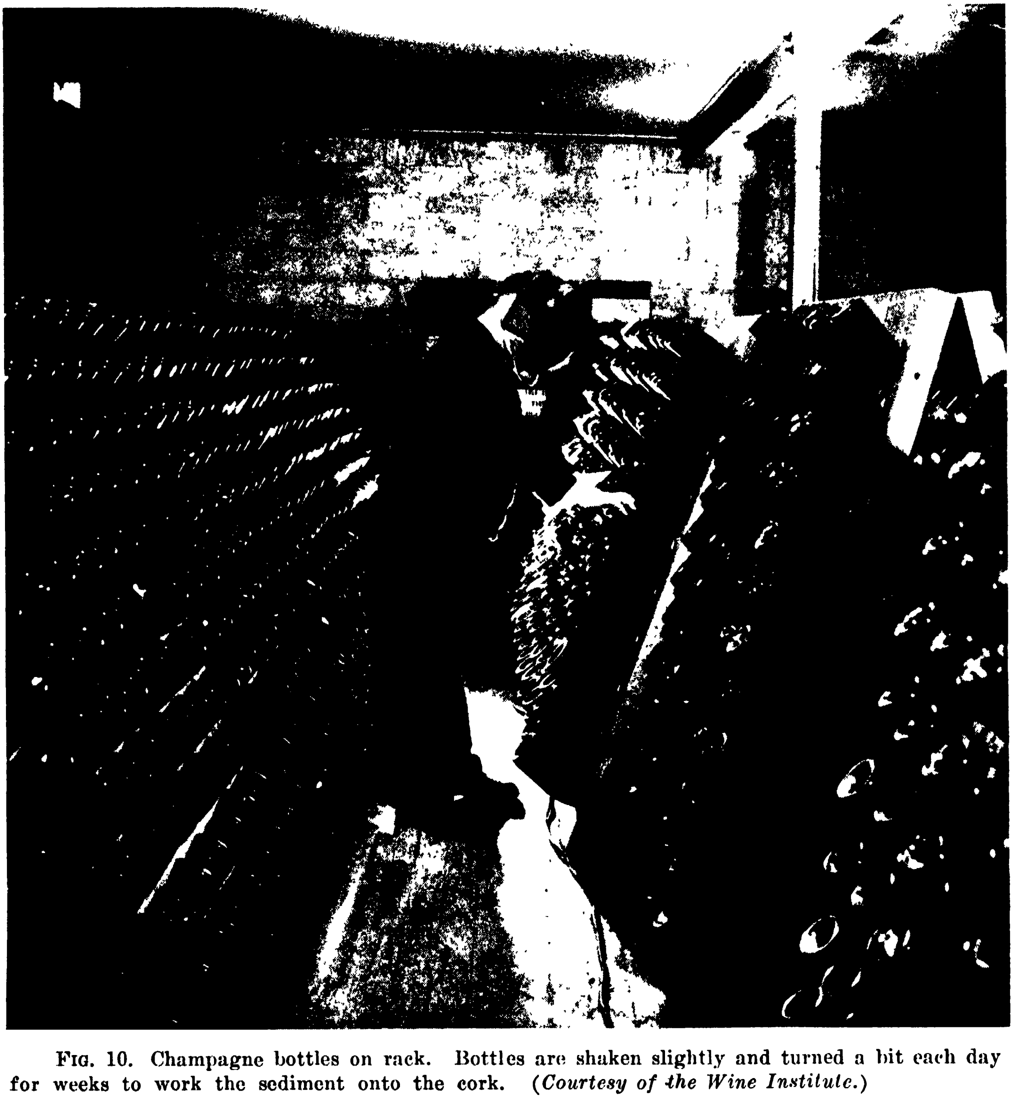

FIG. 10. Champagne bottles on rack. Bottles are shaken slightly and turned a bit each day for weeks to work the sediment onto the cork. (*Courtesy of the Wine Institute.*)

Chemical Constituents. Certain chemical constituents of wines are aids in distinguishing between classes, while others are of use in determining soundness and identity. The alcohol content of table wines must be below 14 per cent, while that of dessert wines is over 18.5 per cent.

The sugar residue is an indication of the completeness of fermentation as well as an indication of the type. Wines with less than 0.2 per cent sugar are "dry", since this amount of sugar is not perceptible to taste. With larger amounts of sugar in the wine, provisions must be made to prevent refermentation or bacterial spoilage. Sweet table wines, according to type, may contain from 0.25 to 6 per cent of sugar. These wines are stabilized by pasteurization, the use of sulfur dioxide, or other means. Dessert wines contain from less than one to 18 per cent of sugar. In these the fermentation is arrested at the desired sugar content by the addition of neutral grape spirits.

Table wines of high total acidity (0.65 per cent or more) taste fresh, fruity and tart, whereas those of low total acidity (below 0.50) are likely to be flat and insipid. Dessert wines, because of their high sugar content, are more acceptable at a lower total acidity. The better ones should have an acidity of 0.40 to 0.50 per cent. A small amount of volatile acid is a normal constituent of wine; it may add to the flavor. However, when the volatile acidity increases unduly (over 0.12 per cent), it becomes objectionable and indicates that the wine is deteriorating.

White table wines are straw to pale yellow, while the white sweet table wines are pale golden in color. An amber tint indicates undesirable oxidation or overaging. The white dessert wines are light amber. Rosé wines are pink in color. Red table and dessert wines should be of a full-red color without blue. Brown is objectionable in all pink and red wines, except in tawny port.

Aromas and Flavors. The constituents that characterize natural wine types cannot be determined readily by chemical means. The flavoring matters and the aroma- and bouquet-contributing substances are present in such small amounts that they have so far been detected only organoleptically, and little has been done to measure them quantitatively. The most obvious and pronounced flavoring substances are those that give the wine its varietal character, such as Zinfandel, Cabernet, Riesling or Muscat. The flavoring substances of these varieties are readily detected in the ripe fruit; those of others, however, are only faintly, if at all, recognizable in the fresh grapes but develop a pronounced character in the wine during aging.

The aroma and flavoring substances of natural wines are principally a combination of aldehydes, alcohols and organic acids. The acids found in wines are acetic, formic, propionic, n-butyric, capric, lauric, caprylic and n-capric. This number of organic acids, as compared to the aldehydes and alcohols, together with their readiness to combine with the same substance or substances to give rise to compounds differing greatly in odor and taste, indicates a prominent role for the acids in, and aids in accounting for the wide variety of flavors and aromas of, wines.

The sherries of commerce are subjected to aging or other treatments which change or add to their natural flavors and aromas. Although the grape variety supplies the suitable base for sherry, much of the distinctive character of the flavor of the Spanish sherries comes from aging under a film of yeast. The film oxidizes alcohol to acetaldehyde and produces other flavoring constituents which enter into the production of the typical sherry flavor. California sherries, on the contrary, derive their characteristic rancid flavor from slow caramelization and oxidation during storage at 120° to 140° F for two to four months. A moderate temperature slows the rate of oxidation and reduces caramelization, with the development of a more delicate flavor. Other wines of this group derive their flavor from long aging in oak casks.

Vermouth is a wine that has been blended with an infusion of bitter and aromatic herbs. The quality of this wine is governed by the quantities and kinds of herbs used, the method of preparing the extract and the character of the base wine. The most commonly used herbs are fruits of coriander (*Coriandrum sativum* L.), bitter orange peel (*Citrus Aurantium* L.), leaves of Roman wormwood (*Artemisia Absinthium* L.), bark of cinchona (*Cinchona* sp.), European centaury (*Centaurea* ?), calamus root (*Acorus Calamus* L.), roots of elecampane (*Inula Helenium* L.), elder flowers (*Sambucus* sp.), fruits and roots of angelica (*Angelica Archangelica* L.), rhizomes of orris (*Iris florentina* L.), roots of gentian (*Gentiana lutea* L.), bark of cinnamon (*Cinnamomum* sp.), cloves (unopened flower buds of *Eugenia caryophyllata*) and the seeds of nutmeg (*Myristica fragrans* L.) and of cardamon (*Elettaria Cardamomum* (L.) Maton). Commonly the herbs are mixed as desired by the producer and then placed in the wine base until it has absorbed the desired flavors and aroma, or the mixture is extracted with alcohol and added in the proper quantity to the wine base.

Aging. Once the fermentation is completed in the case of table wines or arrested in dessert wines, the yeasts and suspended fibrous materials settle rapidly. If held under favorable conditions, the wine next undergoes a series of changes which constitute the development incident to aging.

Timely removal of the wine from the lees—racking—not only aids in its clarification but also prevents the extraction and absorption of undesirable flavors, odors and nutrients from the deposit of yeasts. As the wine will continue to throw additional sediment, the racking must be repeated two or three times the first year and usually two times during the following year or years. In the racking other changes, such as the loss of carbon dioxide and the absorption of oxygen, occur, and these changes again inaugurate other reactions.

Storage in wooden casks of moderate size facilitates the oxidation under conditions that foster normal development of the wine. There is a decrease in the fixed acidity resulting from deposition of acid tartrates and sometimes due to a fermentation of malic to lactic acid; a decrease in the tannins and coloring matter; and an increase in the aldehydes, acetals and similar substances. Once the wine has attained its desired development in the wood, it is bottled. Binning of the bottled (Fig. 13) wine for a time is essential to further esterification and the attainment of a delicate and characteristic bouquet. The proper balance of cask and bottle aging must be determined for each wine. For example, French Burgundy is aged in the wood for a number of years and in the bottle only one to two years, while the reverse is true of French claret.

The period required for aging depends on the type of wine, the nature and extent of the aeration, the size and kind of storage container, and the storage temperature. A wine of high extract and tannin content will age slowly in comparison with a light wine of low tannin content. With small casks and frequent racking, there is an increase in the absorption of oxygen, and aging is more rapid. Over-aeration will result in the absorption of so much oxygen that the wine will taste flat, and if such a condition prevails for a long period the wine will take on an oxidized taste or may spoil. Table wines develop most favorably when stored at temperatures between 50° and 60° F. For dessert wines the temperature may be somewhat higher.

Although table wines of low quality profit but little by aging, since freshness and fruitiness are their greatest assets, aging is of utmost importance for high-quality wines of all types. It is the only means whereby the potentialities of such wines can be brought to their full fruition. Dessert wines of all degrees of quality must be aged in order to ameliorate the grape spirits with the wine and produce a reasonably smooth product.

Clarification. Well-balanced, sound wines usually clear themselves perfectly during normal aging. This may not be true of less well-balanced products. The latter require aids to assist the clarification, such as fining and filtration.

In fining, an agent such as gelatin, isinglass, casein or bentonite is added to the wine. By either combining chemically with the colloids or by physical action these agents cause the suspended particles to coagulate and settle. The proper fining agent must be selected so that the quality of the wine will not be impaired by its action. All such agents take something out of the wine, but their action is different, hence the need for fitting the agent to the particular wine to be fined.

Filtration is a supplement to racking or fining. It is used when the suspended materials fail to settle, or it may be used in conjunction with fining to facilitate the development of ordinary bulk wines for early market. Most wines are given a polishing filtration to remove all suspended substances during the process of bottling.

Wine By-Products. Grape spirits, pomace and cream of tartar are the principal by-products in wine production. Of these, grape spirits, obtained from the pomace or lees, is the most widely recovered by-product. Its recovery may be effected by direct distil-

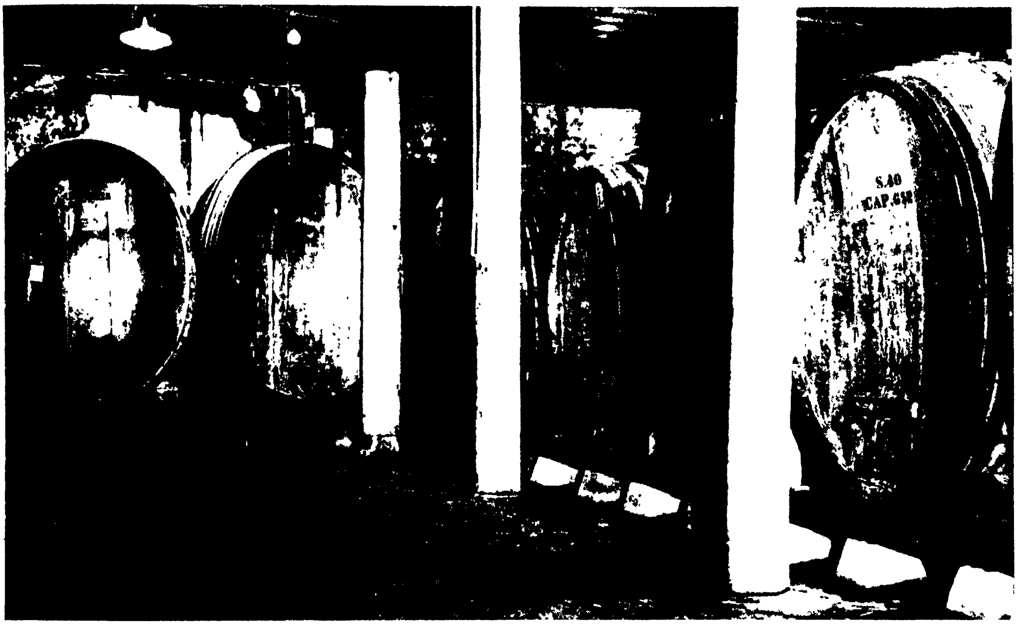

FIG. 11. Moderate-sized oak casks for the aging of quality wines. (*Courtesy of the Wine Institute.*)

lation of these materials or by washing, displacement or pressing and subsequent distillation.

FIG. 12. Huge redwood tanks for the aging of standard wines. (*Courtesy of the Wine Institute.*)

The pomace constitutes $\frac{1}{10}$ to $\frac{1}{5}$ of the weight of the grapes. It may contain some sugar, a small amount of alcohol, or neither, according to the type of wine that is being produced and the general operation of the fermentation room. The bulk of the pomace is skin

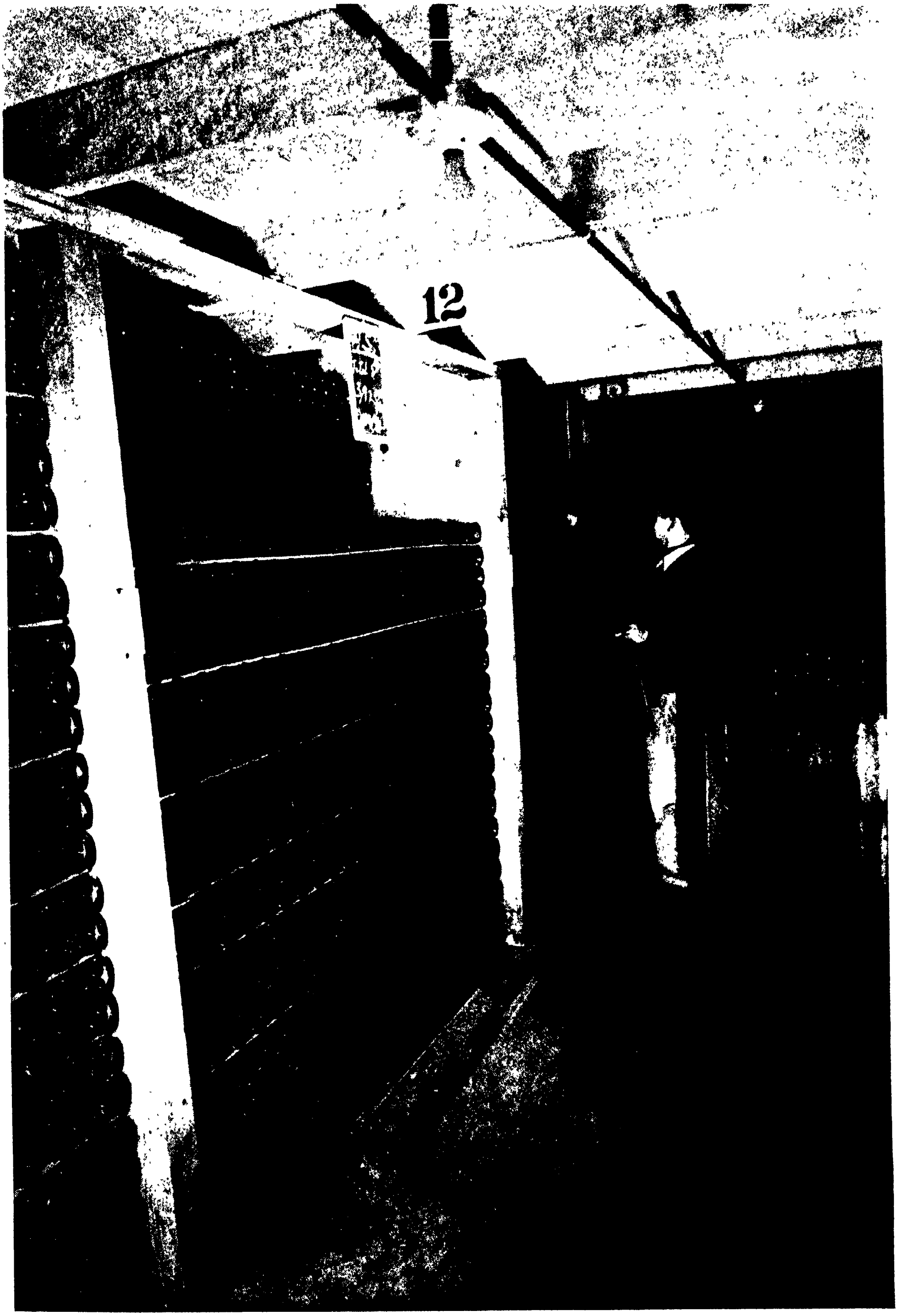

FIG. 13. Placing bottled wine in bins. High quality wines must be given some time for aging in the bottle if they are to attain their highest development. (*Courtesy of the Wine Institute.*)

and seeds; on a dry basis, the skins contribute about 25 per cent of the weight and the seeds 60 per cent.

Fresh pomace contains from 35 to 70 per cent of water and when dry 1½ to 2½ per cent of nitrogen, about ½ per cent of phosphorus, and 1½ to 2½ per cent of potassium. On the basis of its nitrogen content, pomace has a value of about $3.00 per ton applied to the land. As feed it is of little value. Feeding trials with dairy cows have shown that pomace is decidedly low in total digestible nutrients (probably influenced by its lignin content), high in fiber, low in protein and inferior to good roughage in feeding value.

The oil of the seeds in the pomace is extracted in some countries. The content of oil varies between varieties from about 5 up to 12 or 15 per cent of the dry weight of the seeds. The tannin content of the seeds has a similar status. It has value, but there has not been sufficient demand to justify the cost of extraction and purification in America.

Cream of tartar became an important wine by-product during World War II. Previously the only tartrates of American origin were those obtained by the natural separation occurring during the aging and cellar treatment of wine. Many of the wineries of Europe, however, regularly saved all pomace and lees, and scraped their storage tanks to recover cream of tartar. To obtain the cream of tartar from pomace, the latter is thoroughly extracted with hot water, and the extract is treated with calcium chloride to bring about precipitation. The recovery of tartrate from stillage can be fitted into a system for the disposal of this highly putrescible material; the fining, settling and the precipitation of the tartrates should be the first steps in the disposal system.

Utilization Abstract

Flax. The term "linen" includes all yarns spun and fabrics woven from flax fiber; flax is the raw material, linen the manufactured product. Egyptian "mummies 5,000 years old have been found wrapped in linen so fine that it could not be duplicated today . . . The Swiss Lake Dwellers used linen, and in later times the Roman armies used linen rope for bridges as well as for fabrics" . . .

While nearly all European countries do or did produce flax to some extent, Russia is the world's greatest producer of it, with four to six million acres devoted to the crop. Argentine has had up to four million acres; Canada up to two million; and Ireland, Belgium, Japan, Holland and France, 200,000 acres each. Most of this acreage outside Europe is devoted to growing seed flax, the shorter-stalked, more branching variety. This applies also to the United States where in 1947, 4,026,000 acres were harvested, of which, 1,373,000 were in Minnesota. Minnesota and the Dakotas accounted for 85% of all the flax raised in the U. S., and other States with more than 100,000 acres were Kansas, California and Montana. The largest acreage of flax ever gathered in the U. S. was in 1943 when 5,847,000 acres were harvested, yielding about 52 million bushels of seed worth about $150 million. The 1947 U. S. crop was approximately 40 million bushels, worth about $300 million. One third of that was a cash crop in Minnesota.

Except for the relatively small portions of these annual harvests of seeds used the succeeding years for reseeding, the harvests have been utilized in producing linseed oil, so vital in the linoleum, paint and allied industries; and the enormous quantities of flax stalks left over have until recent years been a waste product to be burned or otherwise disposed of. This wasteful situation has been corrected by the manufacture of rugs, cigarette paper, currency, airmail paper and envelopes, and Bible paper from the stalks. (*P. R. Moore, Chemurgic Digest* 7(4): 15. 1948).

Essential Oils—*A Brief Survey of their Chemistry and Production in the United States*

Essential oils can be produced in this country, but extensive investigations and careful planning are of prime importance.

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California Institute of Technology

Introduction

The essential oil industry occupies a very prominent position in our life. Almost continually we are reminded in some way of its products, such as perfumes and flavoring agents. The importance of these substances can hardly be overestimated, and in the past, wars have been fought to obtain sources of and markets for the essential oils. While at the present time other oils have the doubtful honor of being fought about, the past few years have made us feel again how dependent our civilization is on the use of cosmetics and flavoring agents. Due largely to historical reasons, the regions around the Mediterranean have long been the center of the industry, and only gradually have other countries decided to produce some of the oils themselves. Most of these foreign industries are working with low paid labor. Often farmers with their entire families, young and old, collect plant material for wages amounting to a few cents per day. Countries such as the United States with much higher minimum wages are therefore at a great disadvantage in the building up of similar industries of their own. If calling for tariffs, to balance somewhat the advantage of foreign cheap labor, is deemed undesirable, it is necessary to utilize all the scientific and engineering knowledge available to overcome this handicap. In the following we shall point out some cases where against heavy odds, through basic studies of all phases of the problem, successful industries were founded. Before doing this, however, it is necessary to outline briefly our present day knowledge in this field.

Occurrence and Extraction of Essential Oils

Occurrence. Microscopic examination of plants with characteristic odors shows that distinct cells or spaces in the plants are filled with oily droplets which stain with fat dyes. There are, however, two great differences which distinguish these oils from fatty oils: their characteristic odor and their volatility. Evidently the oil is the carrier of the ''essence'' of the plant, and the oils have therefore been referred to as ''essential oils''.

In many cases the cells which contain the oils are epidermal cells or modifications of these, such as excretion hairs, with the secretion product usually accumulated between the cuticle and the rest of the cell wall. A slight touch is sufficient to break this thin outer membrane and to release the oil with its typical smell. In other cases the oil is lodged in internal glands which are distributed throughout the plant and which have been formed by deposition of the oils between the walls of the cells and by dissolution of the surrounding cells (4).

If the essential oils are contained in easily ruptured cells of the epidermis, simple pressing, as is practiced on a large scale in the lemon and orange oil industry, will release the oil. Plants containing the oil in cells distributed throughout the plant, the walls of which are often reinforced with cork, need grinding and cutting before the oil can be released.

In some cases the volatile products are not present originally in the plant material but are formed by hydrolysis from glucosides. Upon grinding the cells, enzymes are set free to split off the volatile products, such as methyl salicylate and benzaldehyde, which are, respectively, the main constituents of wintergreen oil and peach kernel oil.

Steam Distillation. The method most frequently used to separate the volatile oil from the plant is steam distillation. The distillation is carried out in a still consisting of a metal or wooden retort or vat, a condenser and a receiver. In its simplest form the method consists of packing the ground or cut material together with some added water into a still, heating the outside of the still and condensing the vapors evolved. These primitive methods are still used in many countries, but in the more modern methods the water necessary for carrying over the oil is produced in separate generators, and the steam is blown through the plant material which has been packed in the still. The steam heats the plant material and volatilizes the oil, and steam and oil vapors together are condensed and collected in a small receiving flask where the oil separates and forms in most cases a layer on top of the water. The water is released from an opening at the bottom of the receiver through a bent tube, the outlet of which is on a level with the top of the oil layer. In this way the distilled water flows from the receiving vessel as it enters the condenser, while the oil layer remains in the flask and steadily increases in volume until the plant material has become exhausted, usually within two hours. This method is applied in the United States to the production of oils of turpentine (from resin of *Pinus palustris* mostly), peppermint (from leaves of *Mentha piperita*), eucalyptus (from leaves of *Eucalyptus* sp.), cedar (from heartwood of *Juniperus virginiana*), erigeron (from entire plant of *Erigeron canadensis*), witch-hazel (from the young branches of *Hamamelis virginiana*), wormwood (from entire plants of *Artemisia Absinthium*) and lemon grass (from leaves of *Cymbopogon citratus*).

The advantage of the steam distillation method lies in its lower temperature at which the oil components distil as compared to distillation without water. For example, in the distillation of oil of turpentine the main constituent, α-pinene, boils at 155°–156° C. at atmospheric pressure but distills over at 96° C. upon steam distillation.

Sievers (13) described in detail a still which can be used for the commerical distillation and pilot experimentation of a few acres of essential oil plants. For those who have only a small plot of essential oil plants and who want to have the pleasure of distilling their own oil, a still can be constructed at small expense from a ten-gallon milk can, a metal tube for condenser, a smaller can for developing steam and a decanting bottle connected as in Fig. 1.

Enfleurage and Solvents. When flowers are subjected to steam distillation considerable destruction of their odoriferous principles takes place. In such case extraction with fat, or preferably with low boiling solvents like petroleum ether and benzene, is used.

In a number of cases neither steam distillation nor extraction will give a satisfactory yield of oil because the volatile material is produced while the plant is living and only small amounts are stored in the plant tissue. This is, for example, the case with the odors of tuberose (*Polianthes tuberosa*) and jasmin (*Jasminum* spp.). We must give the flower the opportunity to continue to live and excrete its odoriferous components in order that we may collect them. The perfume industry in southern France solved this problem by using the property of fats to absorb the fragrant substances. This so-called "enfleurage process" is carried out in the following manner.

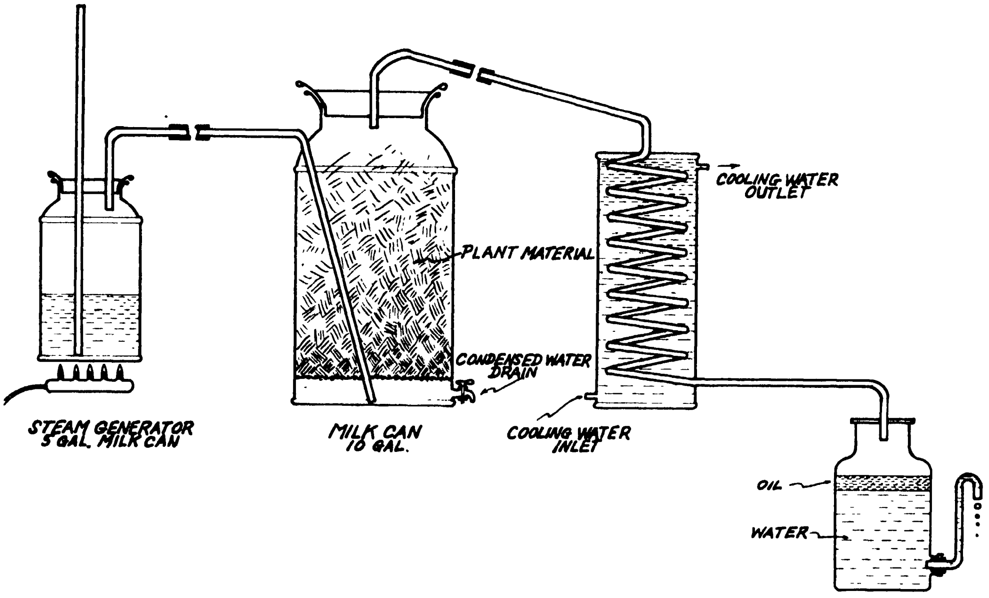


FIG. 1. Diagram of a simple distillation apparatus for home extraction of essential oils from plant material.

Glass plates, two or three feet square in wooden frames, are covered on both sides with purified tallow or lard; on this the flowers are spread. Large stacks of these plates are piled one upon the other about two inches apart. The flowers are left for one or two days completely surrounded by the fat, and are then replaced by new ones. The fragrant substances from several dozen successive layers of flowers are absorbed by the fat, and the fragrant principle is then extracted from the fat by means of alcohol in which the fat is insoluble. Subsequent concentration of the alcoholic extract gives one of the most expensive products of perfume manufacture.

Chemical Composition of Essential Oils

By definition the essential oils are volatile products obtained from plants. It is clear from such a definition that this group will harbor a large number of substances of totally different chemical structure. However, the requirement that the compound be volatile limits the possibilities considerably. Because of this limitation we must look for members of this group among compounds of a boiling point not much higher than 300° C., which means that the number of carbon atoms in these compounds rarely exceeds twenty. This excludes fats, sterols and other higher molecular fat-soluble materials. The compounds can not be too highly hydroxylated, thereby excluding sugars, glycosides and carbohydrates. Strongly ionized compounds, namely, salts, strong acids and strong bases, are not found among the components of the oils. However, within these limits set by the definition the variety of compounds is still very large, including substances which belong to a great number of classes of organic compounds: aliphatic and olefinic hydrocarbons with their derivatives containing oxygen, nitrogen and sometimes sulfur; aldehydes; ketones; alcohols; acids; esters; lactones; amines; mercaptans. Many of them have ring systems containing usually five or six carbon atoms in the ring; other compounds have one of these ring carbon atoms replaced by a nitrogen or by an oxygen atom.

It is not practical to classify this wide variety of substances according to their chemical characteristics. However, one can classify them on a biochemical basis by grouping them as compounds which are related through their biosynthesis. In this way compounds composed of a straight chain of carbon atoms, regardless of their oxidation state and therefore including alcohols, aldehydes, ketones, esters and acids, are discussed together.

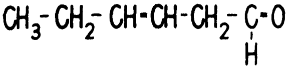
We find hydrocarbons as low as heptane in *Pinus Jeffreyi*, for instance, the oil consisting nearly wholly of this compound and thereby closely resembling normal gasoline. Other turpentines contain nonane and undecane, and there are oils wherein small amounts of higher hydrocarbons have crystallized out. These precipitates are known as "stearoptenes", and some of these contain molecules with as many as 29 carbon atoms and 60 hydrogen atoms. Alcohols, aldehydes, acids and their derivatives of the straight chain type are widely distributed, especially in fruit flavors. Interesting members of this group are leaf alcohol and its aldehyde (Fig. 2, I & II). Homologues of these alcohols and aldehydes are the major constituents of cucumber oil which consists largely of nonadiene-2,6-ol-1 (Fig. 2, III) with some of the corresponding aldehyde.

Another large group, containing carbon atoms with a benzene ring, are important in the perfume and flavor industries. Representatives of this group are to be found in the oxygen derivatives of benzene, such as benzaldehyde (Fig. 2, IV), the main component of bitter almond oil (*Prunus Amygdalus* var. *amara*) and vanillin (Fig. 2) the aromatic principle of vanilla beans (*Vanilla* spp.). A large subgroup contains a benzene ring substituted with a straight chain of three carbon atoms, mostly a propenyl chain. Representatives are found in oil of cloves (*Eugenia caryophyllata*) and sassafras oil (*Sassafras albidum*) which contain, respectively, eugenol (Fig. 2, VI) and safrole (Fig. 2, VII).

In the third group we can place about 500 compounds which have as elementary building units a branched C_5 chain. To this group belong the terpenes which are so characteristic for a number of essential oils, such as turpentine and peppermint. In the last category we must group all those compounds which do not find a place in the other three groups. These are the mercaptans and thio ethers, which are heterocyclic compounds containing nitrogen as well as oxygen in the ring. Examples are found in the occurrence of indole (Fig. 2, VIII) in several flower oils. Asafetida, the gum resin of *Ferula assafoetida* which has been the notorious ingredient of many historical recipes, contains an allyl secondary butyl disulfide (Fig. 2, IX).

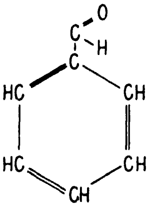
The terpene group is certainly the most typical of the essential oil components, and for a through understanding of the essential oil problems it is necessary to describe more fully their chemical structure. The molecules of a large

$CH_3-CH_2-CH=CH-CH_2-CH_2OH$ LEAF ALCOHOL (I)

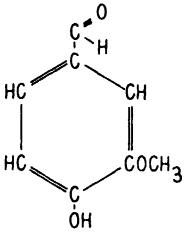


$CH_3-CH_2-CH=CH-CH_2-\underset{H}{C}=O$ LEAF ALDEHYDE (II)

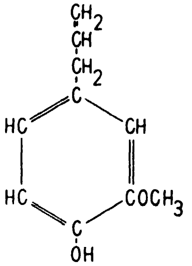
$CH_3-CH_2-CH=CH-CH_2-CH_2-CH=CH-CH_2OH$ NONADIENE-2 6-OL-1 (III)



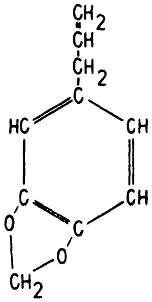
BENZALDEHYDE
(IV)



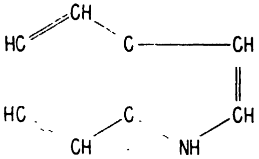
VANILLIN
(V)



EUGENOL
(VI)



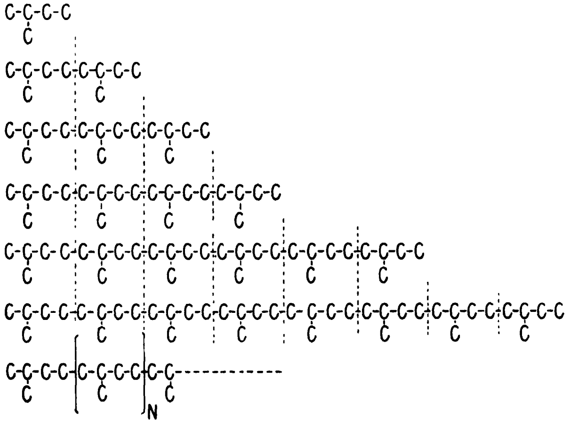
SAFROLE
(VII)



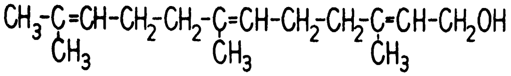
INDOLE
(VIII)

$CH_3CH_2CH(CH_3)S\cdot SCH{:}CHCH_3$

ALLYL SEC BUTYL DISULFIDE
(IX)



HEMITERPENES	5
MONOTERPENES	10
SESQUITERPENES	15
DITERPENES	20
TRITERPENES	30
TETRATERPENES	40
POLYTERPENES	N-500-2000



$CH_3-\underset{CH_3}{C}=CH-CH_2-CH_2-\underset{CH_3}{C}=CH-CH_2-CH_2-\underset{CH_3}{C}=CH-CH_2OH$ FARNESOL (XXII)

FIG. 2. Formulae of some organic compounds associated with essential oils.

number of terpenes are composed of a multiple of 5-carbon atoms, and have the formula $(C_5H_8)_n$ in which n might be 1, 2, 3, 4, 6, 8 and even 500–2,000, as in the polyterpenes such as rubber. The carbon skeletons of the different groups, from hemiterpenes to polyterpenes, with their names are listed in Fig. 2. The carbon atoms are arranged in the pattern of an unsaturated branched chain

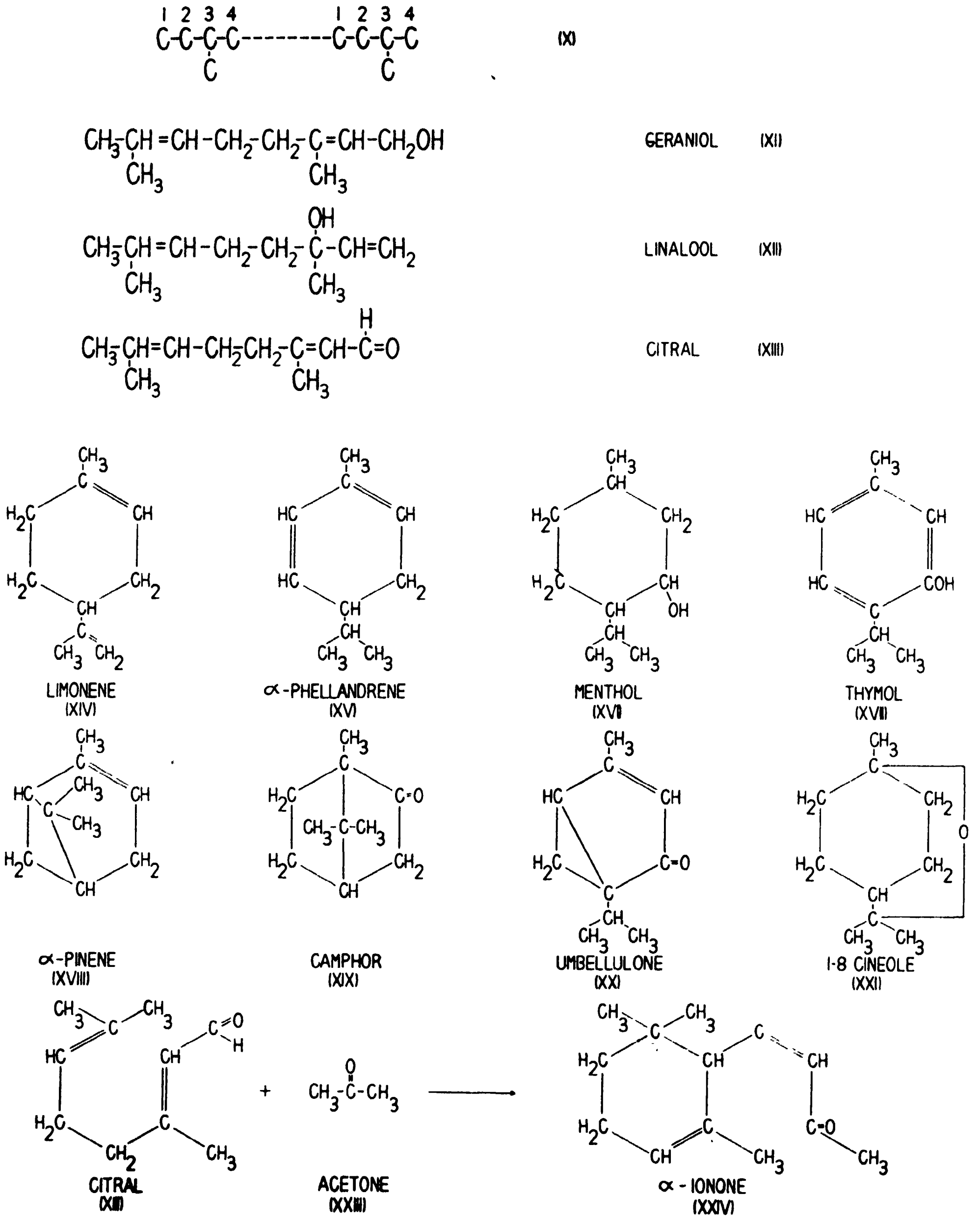


FIG. 3. Formulae of some organic compounds associated with essential oils.

composed of identical units of five carbon atoms. The most important group in the volatile oils is the C_{10} group, in which we usually have a so-called head-to-tail union of these C_5 units. That is, carbon 4 is united with the carbon 1 from another C_5 chain, forming a chain of eight carbon atoms with two methyl groups branching from the main chain (Fig. 3, X).

Hydrocarbons of this type occur in few oils; more frequent are the oxygen derivatives. Some of the most valuable perfume ingredients belong to this group. The structure of geraniol, a component of rose oil; linalool, present as acetate in lavender oil; and citral, the main constituent of lemon grass oil, are also presented (Fig. 3, XI–XIII). Apart from the oxygen present in all three compounds, the presence of the double bonds should be noted. These double bonds are an indication of the unsaturated and therefore reactive character of these substances. Due to this reactivity the carbon atoms in a molecule might give rise to additional linkages with the formation of mono- and bi- cyclic ring systems. Many of these ring compounds occur in nature, although at present it is not known whether this ring closure takes place during the synthesis or secondarily after the open chain has been formed. Limonene (Fig. 3, XIV), containing one carbon ring, is a most common component of essential oils, and is a major constituent of orange and lemon oils. An alcohol of the same grouping is menthol (Fig. 3, XVI), present in peppermint oil. A phenol, thymol (Fig. 3, XVII), with strong disinfecting action is present in thyme oil. If two more carbon atoms are interlinked in the molecule we obtain compounds with two rings. One of these bicyclic types, α-pinene (Fig. 3, XVIII), is found as the major component of commercial turpentine and is one of the most widely distributed terpenes. Other representatives containing two rings are camphor (Fig. 3, XIX), present in the oil of *Cinnamomum camphora* and many other oils, and umbellulone (Fig. 3, XX), the active principle of California bay oil (*Umbellularia californica*) which causes a severe headache within a few seconds of inhalation, due to a sudden rise in blood pressure.

The next class of terpene compounds contains three C_5 units and are called "sesquiterpenes", since they contain one and one half times as many carbon atoms as the monoterpenes. The sesquiterpene group is less volatile than are the monoterpenes and is to be found among the higher-boiling fractions of the essential oils. One of the most valuable of the sesquiterpenes is an alcohol, farnesol (Fig. 2, XXII), which is built like geraniol but contains one more five-carbon group. It has, like geraniol, a flowery smell, which is, however, not so intense, and more closely resembles lily-of-the-valley. The addition of five carbon atoms increases the possible number of isomers which makes the study of these compounds considerably more difficult. Nevertheless the chemical workers could establish regularities in molecular structure similar to those found in the terpene series. Here, too, an interlinking of the carbon atoms is frequently seen, and as a consequence, the occurrence of cyclic derivatives. In this group belong the compounds which give to some oils, such as chamomile (*Matricaria Chamomilla*), spike (*Lavandula latifolia*) and camphor (*Cinnamomum Camphora*), their blue or green color. These colors are not, as was formerly supposed, due to the copper content originating in the stills, but to intensely blue hydrocarbons called "azulenes" with the formula $C_{15}H_{18}$. It is interesting to note that similar compounds are formed upon cutting some mushrooms. In general, this group of sesquiterpenes does not have the strong and characteristic odor of the more volatile monoterpene group. However, the C_{15} compounds play an important role in preventing the more characteristic smelling, lower boiling components from evaporating too fast, and they therefore act as natural fixatives. On the other hand, cases are known, as for example in cedarwood oil, where the sesquiterpene itself is responsible for the typical and highly valued odor.

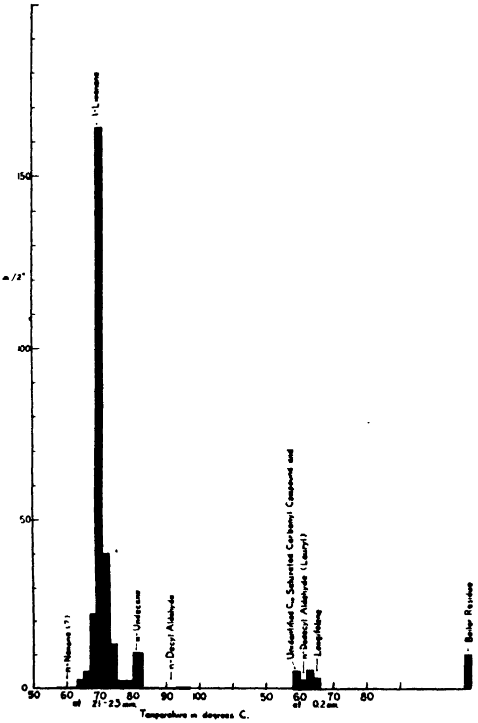


FIG. 4. Straight chain hydrocarbon and terpene composition of turpentine from *Pinus Torreyana*.

The next group of compounds containing four C_5 units we find in small quantities in the highest boiling fractions of the essential oils. Because of the high boiling point of the oxygen derivatives, these are not found in the volatile parts of the oils but are present as rosins and kopals in the residues of the turpentine distillation.

Even less volatile are higher members of the terpenes. These are therefore not of immediate importance to the essential oil industry but are mentioned to round off the total picture of this group of biochemically related compounds.

Molecules containing 30 carbon atoms built along the same principles as the terpenes are found among the saponins. Many drugs, such as sarsaparilla from the dried roots of *Smilax aristolochiaefolia* and *S. Regelii*, owe their pharmacological and detergent action to the presence of these compounds. Still higher isoprene homologues are found in the group of carotinoids (C_{40}), the red and yellow plant pigments. The terpene series is closed with the polyterpenes which contain up to thousands of C_5 units. In this group belong the naturally occuring rubbers.

In the chemical study of the oils, steam distillation is usually followed by a fractionation process which separates the oil components according to their boiling points. To obtain quickly an idea of the composition of an oil, we can represent the fractionation data in a graph, such as Fig. 4, where the ordinate represents the percentage of oil distilling over at an interval of one degree. As illustration of such a fractionation, the results of a systematic study on the composition of the turpentines of the genus *Pinus*, undertaken by N. Mirov and the author, were selected. It has been shown that most turpentines are rich in α-pinene (Fig. 3, XVIII). There are, however, oils which differ radically from the usual pattern. In some cases, as was mentioned earlier, we find that the oil consists of nearly pure normal heptane. The Torrey pine turpentine, as seen from Fig. 4, consists of a mixture of the two major groups—straight chain hydrocarbons and terpenes. In the first place we notice the monoterpene, limonene (Fig. 3, XIV), and the sesquiterpene, longifolene, and superimposed on these are the straight chain hydrocarbons, nonane, undecane and their oxygen derivatives, decyl and lauryl aldehydes.

An example illustrating a different combination of major groups, the simultaneous occurrence of the terpenes and the benzene derivatives, is seen in the analysis of California bay oil (*Umbellularia californica*). The main constituents are the terpenes umbellulone (Fig. 3, XX) and cineole (Fig. 3, XXI). The benzene group is represented by safrole (Fig. 2, VII) and by a methyl derivative of eugenol (Fig. 2, VI).

Conversions of Oil Components

Knowledge of the chemical composition of essential oils is of importance for judging the possibilities in new oil projects as well as in established ones. The chemist is able to convert many oil components into other compounds which may have greater commercial application. Interesting examples are found in the conversion of the terpene alcohol geraniol (Fig. 3, XI) into linalool (Fig. 3, XII), and *vice versa*. Both compounds are valuable perfume constituents, and, depending on market conditions, the reaction can be conducted in such a way that geraniol is converted into linalool which finds use as acetate in lavender composition, or linalool may be converted into geraniol and its esters which are used to impart a rose note to many floral compositions.

Oils containing citral (Fig. 3, XIII) derive a great deal of their importance from the versatility of this aldehyde. It is possible to prepare from this lemon smelling substance rose-like geraniol (Fig. 3, XI), while by addition of acetone (Fig. 3, XXIII), ionone (Fig. 3, XXIV), which smells like violets, can be formed. Other examples are the large scale conversion of α-pinene (Fig. 3, XVIII) from pine oils into camphor (Fig. 3, XIX), and the oxidative degradation of eugenol (Fig. 2, VI) from oil of cloves to vanillin (Fig. 2, V).

One of the most common terpenes, limonene (Fig. 3, XIV), abundantly available in lemon and orange oils, has often been studied from this point of view. Desirable conversion products are thymol (Fig. 3, XVII) and its hydrogenation product, menthol (Fig.3, XVI). Both substances can be made from limonene, but also from other sources, such as umbellulone (Fig. 3, XX) from bay oil and α-pinene (Fig. 3, XVIII) from turpentine, and time will show whether these processes are commercially profitable. More recently special attention has been paid to converting the cheaper oil constituents into polymerization products to serve as plasticizers, plastics, *etc.*

Variations in Composition of the Oils

It is fortunate that the composition of any type of oil varies to a large degree and that the variations can be brought about by different agricultural and climatic conditions and through the use of related species and hybrids. Through the proper choice of these conditions and of plant material it is therefore possible to grow plants which contain the most valuable oil in the highest percentage.

An excellent example of such an investigation to establish the optimum commercial opportunities for a given type of oil has been carried out by Penfold and Morrison (5) in Australia. Due to the abundance of the species of *Eucalyptus*, a great deal of effort has been made in the study of this genus of the family Myrtaceae. This investigation was not limited to the analysis of the most common species. On the contrary, of the 500 species and 150 varied forms, the oils from about 200 species were investigated.

The results of these chemical studies showed that the oils contain a variety of components, 50 of which have been well characterized. On the basis of these findings the *Eucalyptus* oils have been classified into three groups:

I. Oils containing cineole (Fig. 3, XXI), used for inhaling in the treatment of colds.

II. Oils containing a large percentage of phellandrene (Fig. 3, XV) and less than 70% cineole. These oils are used mostly for their solvent properties, as in cleaning solvents and insect sprays.

III. Oils containing a large percentage of terpenes of the acyclic type, such as citral (Fig. 3, XIII), its reduction product citronellal and the acetic acid ester of geraniol (Fig. 3, XI). Their low content of the camphor- and mint-like smelling substances of the *Eucalyptus* in groups I and II makes this oil valuable to the perfume industry.

Studies on the influence of climate and soil upon the formation of essential oils in plants were also made. Also studied was oil formation in the different stages of development of the plant. In general, it has been shown that the highest production of oil occurs during intensive growth. The composition of the oils, too, is subject to different growth conditions, as was shown by the Australian work on the oil of young *Eucalyptus* leaves. Some compounds in these oils, such as the terpene hydrocarbon phellandrene, may appear during spring and summer only to disappear completely towards winter when oxidation products take its place.

In these studies the interesting observation was made that morphologically identical trees contain greatly different oils. A systematic survey of the oils from individual trees showed that four entirely different compositions could be found. How widely different these compositions are can be seen from the following tabulation cited from Guenther's monograph on Australian eucalyptus oil (5):

E. dives Type contains about 50 per cent piperitone, no cineole and almost 40 per cent phellandrene.
E. dives var. "A" contains about 5 per cent piperitone, no cineole and about 75 to 80 per cent phellandrene.
E. dives var. "B" contains 10 to 20 per cent piperitone, 25 to 45 per cent cineole and a quantity of phellandrene.
E. dives var. "C" contains less than 5 per cent piperitone, 60 to 75 per cent cineole and no phellandrene.

Especially interesting is the difference between the oils of varieties "A" and "C". One is a good industrial solvent, while the other, on account of its high cineole content and the absence of phellandrene, qualifies as a medicinal oil. This knowledge is of great importance for the collecting of the oil, since proper selection of the trees makes for greater homogeneity in the product. Similar findings were made in the species *Eucalyptus radiata* and *E. Australiana.*

That such a biochemical difference between trees which are indistinguishable by morphological characteristics is more common, can be seen from our studies of the compositions of the oleoresins collected from *Pinus washoensis.* The trees were growing close together on Mount Rose overlooking Lake Tahoe, and the morphological study of the trees left no doubt as to their identity. However, some of the oils were laevo-, others, dextro- rotatory. Chemical analysis showed that some of the oils contained a large percentage of Δ^3 carene, while this terpene was nearly absent from others and replaced by β-pinene.

Lemon-Grass Oil in the United States

In the United States the development of the lemon-grass industry shows a similar understanding of the basic problems involved, and a great deal of thorough research was carried out before large scale planting of the essential oil-bearing plants was started (2, 3, 10). It is interesting to review briefly its development because it shows clearly the difficulties that the essential oil industries face in this country.

To find year-round employment for agricultural workers, the United States Sugar Corporation and the U. S. Dept. of Agriculture in Florida were looking for a suitable enterprise. In 1934 cultivation and distillation of lemon grass (*Cymbopogon citratus*) was selected as a promising possibility. To show one of the main difficulties of this project I quote Dr. Bourne: "A rather comprehensive study of labor costs in foreign countries supplying the American market with duty-free oil was next made. With agricultural workers in the lemon grass industry receiving between 8 cents and 25 cents daily in these foreign countries and then shipping the oil duty-free to America to compete with agricultural laborers in the area receiving a minimum of $1.60 daily wage plus housing, medical assistance and several other perquisites, many innovations for saving excessive and expensive labor costs were naturally sought to overcome this unfair competition".

On experimental plots the amounts of potassium, phosphorus and nitrogen were determined with which the local soil would give a maximum yield in oil. In this way with the best fertilizer combinations, in the period of June 8 to October 1 (1936), yields of 43 tons of green lemon grass per acre were obtained. The amount of lemon-grass oil per acre amounted to about 150 pounds. Studies were then made on planting, cultivation, harvesting, loading and transportation procedures. Harvesting machines were built which could harvest and load in baskets placed in each field wagon. At the processing plant these baskets are lifted and placed in the stills where steam removes the oil. In all of the operations the grass is never touched by hand.

In 1939 the price of foreign oil f.o.b. New York was as low as 35 cents per pound. Even with the improvement in agricultural and processing methods commercial production at a profit was out of the question. Efforts were made to develop by-products. It was found that dehydrated lemon-grass pulp containing 35% cane molasses makes an excellent feed for finishing beef cattle in Florida when supplemented with small quantities of a protein concentrate.

In 1941 Dr. Bourne wrote: "In view of the successful by-product utilization, and the establishment of the industry on the basis of both oil and cattle feed, competition with foreign producers can now be fairly met. The industry has therefore been expanded considerably in order to supply American producers in this time of crisis with a secure source of fresh oil having a minimum of 75% citral content and also give the cattle men of Florida a reasonably priced feed product for finishing steers economically".

How timely this lemon-grass project proved to be is shown by the fact that while in 1938 the imports of lemon-grass oil amounted to half a million pounds, during the war this continent alone was the main supplier through its plantations in Guatemala and in Florida. This enterprise was hailed as a real contribution to the independence of the United States in the raw materials of the oil industry and was praised for its founding on real business economics.

In 1945 we find another article by Dr. Bourne. During the intervening period the lemon grass industry went through a boom period, when in August, 1942, \$4.35 per pound of oil was paid. But only six months later this price was reduced to \$1.15 per pound. In 1943 the price fell as low as \$0.64 per pound. Notwithstanding all the ingenuity with which the lemon-grass industry was created, a loss was sustained during these years, due to the increased costs of labor and material. An industry is described which at its birth had some good fairies, such as the sugar industry and the U. S. Dept. of Agriculture, at its bedside. A great deal of ingenuity is shown overcoming all kinds of technical difficulties. Economically it fills a necessity in supplying year round employment in conjunction with the sugar industry. Nevertheless such an industry is fighting a losing battle. The scientist would do well to recognize that, when he has carried his task to perfection, the economic conditions will ultimately determine the viability of the enterprise.

In a considerably better position are those oil industries which were created as outlets for by-products. In the United States we find an excellent example of this type in the utilization of the by-products of the citrus industry. In a review in this journal by Glen H. Joseph (11) it was pointed out that "Wisdom in planning with confidence, foresight and patience in research and development, converted a botanical wastage to a national industry doing an annual business of more than \$125,000,000. Students of economic botany may well pause to review this example of chemurgy as an illustration of the possibilities in their respective phases of this field". The hundreds of references to be found yearly in Chemical Abstracts testify to the tremendous volume of work that has been and is being done in this field. Although the citrus industry is primarily based on the consumption of the fruit as food, the research program has produced so many useful by-products, such as essential oils, pectins, pectates, citric acids, flavanone-glucosides, molasses and stock food meal, that the by-products now form a valuable part of the industry.

Other essential oils produced as by-products of a main industry are cedarwood oil and pine oils. The wood of the red cedar (*Juniperus virginiana*) contains a volatile oil known as "cedarwood oil". This oil is used extensively in the manufacture of perfumes, soaps and insect repellants. The oil is usually obtained commercially by distilling the sawdust and other wood wastes from the manufacture of cedarwood products.

Oil of turpentine constitutes the largest volume of oil produced in the United States. Its use as a solvent is well known. Important contributions to the conversion of the main components of the oleoresins from pine trees are continuously appearing in publications from the U. S. Naval Stores and private companies, such as Dow Chemical.

Conclusion

While this review is largely devoted to successful introduction of the essential oil industry into the United States, a long story could be written about the enterprises, small and large, which had to be abandoned. It is therefore fitting that a review written by Dr. Sievers of the U. S. Dept. of Agriculture (13) concludes its informative chapter on extraction of volatile oils from plant material by warning of the many pitfalls over optimism and lack of knowledge. The necessity of conducting small scale experiments is stressed before undertaking extensive operations when planting in a new region is planned. Thorough calculation of costs and correct appraisals of marketing conditions must be carried out. The fluctuating market value of the oils is determined not only by economic condition but also by variations in the quality of the oils. These variations might be due to unsuitable soil and climatic conditions, or improperly conducted extraction of the oils. Lower grade oils can be sold only at considerably lower prices, and carefully balanced cost estimates are upset. Studies have to be made on the possibility of by-products which sometimes make it possible to make some profit. Nevertheless one should realize that other industries often produce similar products, and here, too, a cold-blooded, sound, business calculation is better than a disappointment after losing an investment.

With these reservations constantly in mind it is safe to look at the other side of the medal and enjoy the activities of many workers in this field published in Chemical Digest, Reports of Oil and Drug Conferences, and in this journal.

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Utilization Abstract

Newsprint from Wheat Straw. "An event that may prove to be one of the greatest achievements in the history of chemurgy occurred recently when newsprint paper was manufactured for the first time in a commercial mill with wheat straw as its entire basic raw material".

This was accomplished by a process developed by The Kinsley Chemical Company of Cleveland, Ohio, and was carried out in September, 1948, at the Chemical Paper Manufacturing Company of Holyoke, Massachusetts. The expected greater utilization of farm residues resulting from this development should contribute much to relieving the present great demand for wood pulp in manufacturing the 21 million tons of paper produced annually in the United States. *Chemurgic Digest 7(10): 4. 1948*).

The Importance of Plant Classification in Hevea

More than 40 years work with one species of Hevea has resulted in great improvement in yield. An organized effort is now being made to select from numerous wild species living material offering new characters for disease-resistance and increase in yield.

RICHARD EVANS SCHULTES*

Introduction

Whenever a plant-utilizing industry is built upon a fragmentary understanding of the quality, potentialities and limitations of wild plant materials which could be made available to it from nature, then only a limited utilization of wild stock results and the progress which might otherwise be effectuated never materializes. Such is the situation in the rubber industry.

Hevea is one of the most recently domesticated of economic plants. Phenomenal improvements in strains of one species in it have been made during the last fifty years, but we may justifiably expect a fuller understanding of *Hevea* in its wild state to open up avenues of betterment and diversification which would astonish the scientific and commercial world. Studies and utilization of wild progenitors in cotton, sugar, potatoes, cereals and many other ancient cultivated plants have produced improvements in these crops, and comparable improvement might be achieved in *Hevea* through greater knowledge of all species in the genus and use of them in hybridization. Few of the specific and subspecific variants of *Hevea* have entered into the programme of the extensive rubber plantation industry which is based almost exclusively on material of *H. brasiliensis* originally from one small area—the Rio Tapajoz—of the vast Amazon Valley.

As a result of the short period—seventy years—of domestication of *Hevea*, the difficulty of travel where *Hevea* is native, and unavailability, until recently, of funds commensurate with the task of adequate exploration, we still lack intensive field studies upon which a definitive classification of the genus may be made.

Plant classification—or taxonomy—is a science. Many people, even today, do not understand its scope nor appreciate its aims. It has two general phases, the academic or theoretical, and the practical or applied. There never can be a sharp boundary between pure and applied science; the one is as important as the other to a scientist, even though one phase may interest him more than the other. While the numerous academic problems in *Hevea*, which only a taxonomic and phylogenetic study can solve, are of profound interest, I shall discuss in this brief article merely the practical value of taxonomy to a dollar-and-cents-conscious industry.

History, Distribution, Characteristics

Hevea is a genus belonging to the Euphorbiaceae, a world-wide family comprising some 7,000 species. *Hevea* leads all other genera in this economic-

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ally important family both from the point of view of financial investment and from that of influence on human progress. Native to South America and there confined to the Amazon Valley and several contiguous regions, *Hevea* inhabits an area three quarters the size of the United States.

Its taxonomic history began in 1775 when the French botanist, Aublet, described the genus from French Guiana. He called the type species *Hevea guianensis.* Knowledge of the genus advanced with painful slowness, however, until the field work of that most sacrificing of explorers, the Englishman Richard Spruce, whose collections from the Rio Negro of Brazil, made in 1852–53, provided the material for the description of eight additional species. The earliest synopsis of *Hevea* was published in 1873–74 by Mueller who recognized 11 species. Huber, working along the Amazon in Belem do Pará at about the turn of the century, greatly augmented the number of concepts until there were held to be 24 species. Later Pax classified the genus into 17 undoubted species. The most recent treatment is that of Adolpho Ducke who, after nearly half a century of field investigations, recognizes 12 species and numerous varieties and forms.

Although a relatively small genus, *Hevea* shows a most remarkable range of variation in the wild. Probably geologically a young genus still in a state of evolutionary flux, its classification often poses exasperatingly complex problems. There are a great number of subspecific variations, many of them biologically stabilized and with definite geographical correlations, others mere responses to environmental conditions. By intensive study of large populations in the wild state we may hope to gain a clear insight into the significance of variation in *Hevea.* Since cultivation often tends to induce additional and artificial variation, the only method is to track *Hevea* down in its native haunts. This must be done if we are to take advantage of the wide natural range of variability.

The rubber of *Hevea guianensis* and of *H. guianensis* var. *lutea* is often weak and of limited commercial application, but both the species and the variety show a most extraordinary range of variation. If fully understood taxonomically, these concepts might prove of unexpected significance in breeding work. They are jungle giants and prefer well drained land above the flood level. Some representative variants grow as high as 6,000 feet altitude, and others inhabit uninviting rock and talus slopes which are almost devoid of soil. Although known to science before any other species of *Hevea, H. guianensis,* the most widely distributed species, remains today one of the most poorly understood concepts insofar as definition of its minor variants is concerned.

FIG. 1. The earliest fundamental investigations on the species of *Hevea* were carried out in the Rio Negro area of Brazil by that most self-sacrificing of explorers, the Yorkshireman Richard Spruce. (Drawn by Gordon W. Dillon from an old photograph preserved in the Gray Herbarium of Harvard University).

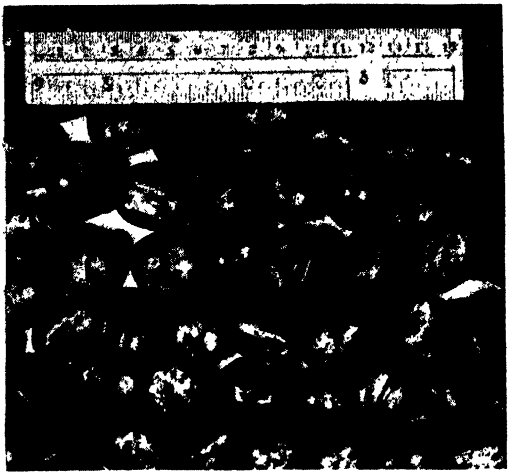
Hevea nitida is a large tree of flood-land jungles, but it may also occur in a varied form in light, highland forests. It yields a latex which coagulates into a sticky mass of no commercial value as rubber. Furthermore, the latex of this species, when mixed with that of other species, acts as an anticoagulant. Yet, in spite of its close relationship to *Hevea nitida,* the recently discovered *H. nitida* var. *toxicodendroides,* a tiny shrub-tree native to bare, dry and sun-baked sandstone hills where only a scrub vegetation can exist, yields a latex which gives a good rubber. Could we not expect the extreme resistance to drought and radiation, the apparent high resistance to leaf blight, the thick, leathery leaves, and the quality of rubber of this diminutive variety to be of value for breeding? *Hevea nitida* and its variants may be of extreme interest to the future breeder because, although it appears very distinct superficially, taxonomic studies indicate that it is rather closely allied to *H. brasiliensis.*

While *Hevea brasiliensis* yields the highest quality and quantity of rubber, the other species have unusual characteristics that might be valuable in experimenting for future plantation stock. The breeder and planter must consider not only yield and quality of latex and rubber; disease resistance; wound response; and other major factors. He must consider also a host of secondary points, such as thickness, softness and anatomical features of the bark as it affects tapping; resistance to wind; root system; utility as root-stock or crown stock in budding; characteristics of the foliage and branching; and innumerable other matters which are not always immediately obvious. The rubber industry must draw upon all of the forms which nature has already evolved. In the past, the experiments which have employed species other than *Hevea brasiliensis* have been few and limited, and opportunities of inestimable significance may thus have been overlooked.

The highly variable *Hevea Benthamiana,* growing usually in the most acidic of permanent black-water bogs, yields a very high-grade rubber. Some varieties and forms of it have very leathery leaflets and seem to prefer dry, sandy habitats. Is there not a hope that thorough study of this concept might produce interesting data for use in disease control or that the species might yield characteristics valuable for producing a clone which could grow in sites unfavourable for *Hevea brasiliensis*?

Other species and varieties might be pointed out as of prime interest to our study. Occurring in great numbers in the most swampy areas of the eastern half of the Amazon Valley, *Hevea Spruceana* is not tapped for rubber because it has a thin, non-coagulating latex. Little or nothing is known of the rubbers produced by *Hevea rigidifolia,* a very small tree of light, sandstone-hill forest and with extraordinarily coriaceous leaves adapted to long dry periods; nor of *H. microphylla,* a small forest tree whose seeds shed gently and not explosively as in all other species; nor of *H. pauciflora* and its numerous variants, inhabitants of rocky slopes and other inhospitable sites. And what may we expect when we are able to study stands of the diminutive *Hevea camporum,* known from only one incomplete herbarium specimen from granitic hills at the headwaters of the Rio Marmellos in Brazil; and when we can rediscover and introduce into cultivation *H. minor* from the Casiquiare?

Little really is as yet known of the minor variations of wild *Hevea brasiliensis* itself. Several varieties have been described, but the concept seems to be so variable that mass studies of wild populations must be made to appreciate the extent and significance of the differences.



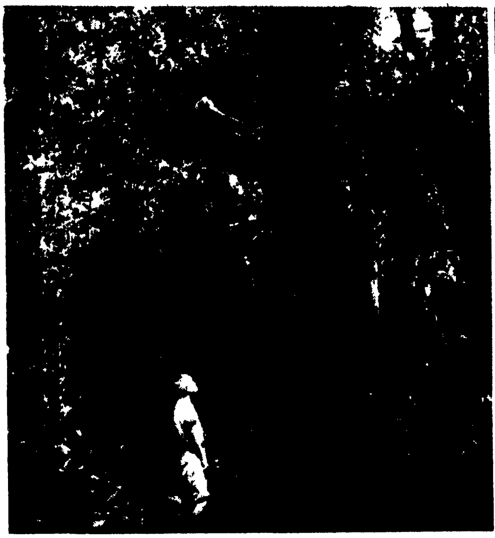


FIG. 2 (*Upper left*). *Hevea* trees may be tremendous giants of the jungle, such as *H. brasiliensis* and *H. guianensis* which often reach a height of 140 feet; or they may be, like *H. nitida* var. *toxicodendroides* in the illustration, diminutive shrubs or semi-prostrate bushes native to open, xerophytic, sandstone mountain-tops.

FIG. 3 (*Upper right*). The collection for nurseries of tons of seed of *Hevea brasiliensis* has afforded botanists an opportunity to study the variation in seeds from native populations of this species. The figure shows one type of seed of *Hevea brasiliensis* from Leticia, Colombia.

FIG. 4 (*Lower left*). An intensive search for outstandingly superior wild rubber trees has been in progress for several years in the Amazon Valley. Suitable branches are cut from selected trees and are sent to central nurseries to provide budding material. The ascent of an enormous tree of *Hevea brasiliensis*, shown in the illustration, is a difficult task because of the height and corpulence of the tree, as well as the many spiny ant-infested air-plants which clothe a great part of the trunk.

FIG. 5 (*Lower right*). Unlike many species of *Hevea*, *H. guianensis* is native to high land which is not subject to four or five months of deep inundation each year. This species is one of the most majestic trees of the high-land Amazonian jungle where it sometimes reaches 125 feet in height.

Recent Investigations

During the last five years the United States Department of Agriculture has carried out, through its Division of Rubber Plant Investigations and in cooperation with the governments of Brazil, Colombia and Peru, an ambitious programme of jungle selection of outstanding wild individuals of *Hevea* which show high yield and disease resistance. It has also encouraged cytogeographic and taxonomic studies. This work has necessarily been concerned chiefly with *Hevea brasiliensis.* But whenever fortune has permitted, material has been selected from as many of the other species, varieties and forms as possible. A significant living collection is being assembled in order that we may have at hand a museum of the wild representatives of *Hevea* for use in scientific programmes. This collection includes *Hevea Benthamiana;* several variants of *H. guianensis* and its variety *lutea; H. nitida;* and a number of others. Recently the extremely rare *Hevea rigidifolia,* not seen since Spruce collected it nearly a century ago on the Rio Negro, has been rediscovered in several localities of the same area. Further explorations may even turn up species as yet unknown.

Thousands of trees have been studied; tons of wild seeds have been gathered; chromosome counts have been made of hundreds of wild trees; and thousands of herbarium specimens, notes and photographs of numerous species of *Hevea* have been prepared. It is fully realized that seemingly academic studies are highly practical, not only to plant breeders but also to chemists. A clear classification of *Hevea* may help the chemist understand differences in properties of the latex of the numerous species, varieties and forms. Chemical differences in latices, while often influenced by ecological factors, are fundamentally correlated with the genetical make-up of the plant.

This is the first time in history that such an extensive programme has been possible with *Hevea.* The success it has met with is due largely to the sustained interest of the cooperating Latin American governments. We feel that we are finally at the dawn of a better comprehension of what *Hevea* really is and of how the genus is constituted. Only continued exploration, however, will enable taxonomy to prepare for science in general and for the rubber industry in particular a final blue-print of this most fascinating of plant groups.

The remarkable expansion of the elastomers of the so-called "synthetic rubber" industry is creating a demand for rubbers and rubber-like substances of all types for use as "fillers" or "softeners". We who are engaged in plant exploration and classification must be on the alert, for perhaps one of the humbler species of *Hevea,* today passed by because its latex is intrinsically of no commercial value, will one day assume an exalted place as producer of a superb softener for some as yet unknown elastomer.

At the present time, in our really incipient stage of knowledge of what the potentialities of the rubber trees of the genus *Hevea* are, we continually refer to the available taxonomic work, incomplete as it is, for any fundamental step in plant-breeding or selection. Should we not strive to provide a more satisfactory and complete classification as the first step in our programme for an overall betterment of the industry?

Roselle—*A Potentially Important Plant Fiber*[1] ✓

Not yet exploited in the Western Hemisphere, this jute-like African fiber possesses commercial possibilities and is obtained from a plant that furnishes also edible fleshy calyces and oil-containing seeds.

JULIAN C. CRANE[2]

Introduction

The roselle plant (*Hibiscus Sabdariffa* L.) is used principally for its bast fibers and for its fruit, the latter being utilized for making jelly and preserves. The silky, soft and light-colored fiber obtained from this plant has practically the same chemical and physical properties as jute (*Corchorus capsularis* L.) fiber and, therefore, offers a very satisfactory jute substitute.

At the beginning of the second World War roselle attracted considerable attention with respect to its being utilized as a quick source of soft fiber for the manufacture of burlap and other fibrous articles. Consequently a comprehensive review of the literature, presented here, was made in order to assemble the world-wide information dealing with the roselle plant and its products. Although statements made in some cases are rather confusing and contradictory, one must remember that the data here reported have been compiled from widely separated locations that have greatly different soil and environmental conditions.

Considerable confusion exists with respect to literature references, several of which, especially from this hemisphere, deal with "roselle", although it has been determined that the plant material discussed was actually kenaf (*Hibiscus cannabinus* L.), a close relative of roselle (9). Although plants of these two species are apparently quite similar regarding cultural and environmental requirements, our limited experience with roselle in this hemisphere precludes comparative evaluation of the material presented here with that which has been published on kenaf (10).

History

In a study of the history of roselle, Wester (46) found that the first published account of the plant was made by the Flemish botanist, M. de L'Obel, in 1576 (31). Wester believed that the species was probably brought westward from India by the Mohammedans who invaded India several centuries before the plant was described by M. de L'Obel. That the plant was from the beginning known by the name "Sabdariffa", a Turkish word, according to Drury (13, p. 252), lends color to this belief. Use of the leaves for greens and reference to its cultivation for fiber first appeared in 1687 (23).

Roselle was reliably reported from the Western Hemisphere at the beginning of the eighteenth century, at which time it was in cultivation (46). Wild plants of *Hibiscus Sabdariffa* that occur in the American tropics would seem to have escaped from cultivated fields. This indicates that the species is not indigenous to the American tropics but is probably of Old World origin.

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[1] The investigations involved in assembling this review were made possible by funds provided through the United States Interdepartmental Committee on Cultural and Scientific Cooperation.

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Probably the first roselle, the tall, unbranched type (var. *altissima*), cultivated for fiber in the Western Hemisphere was grown in Cuba in 1919 (5). The seed for this crop was sent by P. J. Wester from the Philippine Islands to the Cuban Agricultural Experiment Station.

We are led to believe that the culinary uses of the calyces of this species were first recognized in Jamaica in 1707 (41 p. 224), where, it was stated, "the capsular leaves are used for making tarts, jellies, and wine for the treatment of fevers and hot distempers, to allay heat and quench thirst". It is reported that the species was introduced into Florida from Jamaica, probably during 1870 to 1880, and that it was first grown in California about 1896 from seed imported from Australia (46). It is rather odd that roselle was introduced into the Philippine Islands from the Western Hemisphere (Trinidad) in 1905–250 years after it was known in Java. Considerable interest in roselle developed in Florida and California during the early 1900's with respect to the use of the enlarged calyces in jam and jelly making.

Use of roselle for commercial purposes was not recognized until the middle of the last century when it was found to be of value as a source of fiber (40). That the plant attracted but little attention until a comparatively few years ago is shown by the fact that it was not included by A. de Candolle in his "Origin of Cultivated Plants", published in 1882.

Roselle appears to have been a horticultural crop of considerable importance in Queensland, Australia, in 1892, since there were two preserving factories in operation for utilization of the calyces (46). Roselle jam is reported to have been shipped to Europe in large quantities in 1896. Later this industry must have suffered a serious decline, for the Queensland Department of Agriculture Report for 1909 states that there were only 1.6 hectares (four acres) of roselle producing edible commodities.

Description and Nomenclature

Roselle, which produces enlarged edible calyces and the roselle fiber of commerce, is an annual plant belonging to the large family Malvaceae. It is closely related to several genera containing fiber-producing plants, *e.g.*, *Abutilon, Sida, Malva, Althaea, Urena* and *Lavatera*. Its most important relative from a commercial standpoint is cotton (*Gossypium* spp.). Other species of economic value related to roselle include okra (*Hibiscus esculentus* L.), the young fruit of which is commonly used as a vegetable; kenaf (*H. cannabinus*), cultivated for the fiber obtained from the inner bark; and some used for ornamental purposes, of which the Swamp or Rose Mallow (*H. moscheutos* L.) is a common example.

Roselle has been variously called "sorrel", "red sorrel", "East Indian sorrel plant", "thorny mallow" and "various-leaved hibiscus". The assumption by Royle (40) that the name "roselle" is a corruption of the French word "oseille", (the equivalent of the English word "sorrel"), seems well justified. It has been spelled "rouselle", "rosella" (Spanish) and "rozelle". In the commercial trade of some parts of the world the calyces of the edible types of *Sabdariffa* are called "karkade flowers". In India the plant is known under the vernacular names "mesta", "patwa", "lal ambari" and "kempu". The fiber has been called "India rosella hemp", "rosella fiber", "rosella hemp", "rozelle hemp" and "Pusa hemp".

Most of the statements and descriptions concerning roselle refer to a plant with red stems and calyces, the latter being used for culinary purposes. In some articles mention is made of a form with a green or whitish calyx, but no descriptions were given until not only the red and green varieties but also two intermediate forms were differentiated at Pusa, India (25). These intermediate forms are partly red, but in each the localization of the color is different. A form of roselle having light-green stems and leaves with straw-colored or whitish calyces was recorded by Hughes (26, p. 204) almost 200 years ago. How long it had existed before that time is not known.

Varieties

Hibiscus Sabdariffa may be divided into three main groups (see Table 1) on the basis of plant coloration: (*a*) plants of which the stems, petioles and calyces contain a red pigment throughout, which gives the brilliant red color characteristic of all food products made from plants of this type; (*b*) plants lacking this red pigment, all parts of the plant being greenish and the calyces straw-colored or whitish; (*c*) plants which are intermediate between the green and the red types; that is, the stems, petioles and calyces contain red pigment only in certain localized spots or splashes.

The type of plant with deep red coloration is decidedly the most useful for culinary purposes, both because its color is attractive and because the calyx is less fibrous and harsh than in the other types.

Hibiscus Sabdariffa might be further divided on the basis of growth habit into two groups: a tall-growing, unbranched form, the type of plant desired for fiber production; and a shorter, much-branched form, generally used for its edible calyces and leaves. The difference in growth habit is so pronounced in this species that Deshpande (12) believed that the fiber variety described by Wester as *altissima*—the tall unbranched form—might be a different species. He made successful intervarietal crosses between *H. Sabdariffa* var. *altissima* and the short much-branched varieties selected by Howard and Howard (25), in order to determine whether there is an affinity between the two forms.

Although the culinary and fibrous uses of roselle have been known for a considerable length of time, the division of the species into different varieties has been comparatively recent. No varieties of roselle appear to have been selected until the culinary variety Victor was isolated and named in 1907 (45). This variety originated among a number of seedlings grown at the Subtropical Laboratory, Miami, Florida. The culinary variety Rico was named and illustrated for the first time in 1912 (47). Two other culinary varieties, Archer and Temprano, the latter being originated at the Lamao Experiment Station in the Philippines, were described by Wester (48) in 1914. The Temprano, an early maturing red variety, was selected from a planting of the Victor variety, while Archer, characterized by all parts of the plant being greenish or whitish, was originated from seed received from A. S. Archer, of Antigua, British West Indies.

Howard and Howard (25) in 1911 selected four varieties of roselle and found them to breed true. With the exception of a slight difference in the form of the calyx in *H. Sabdariffa* var. *bhagalpuriensis* and differences in color, these workers found the four varieties to be absolutely identical in all "morphological and agricultural characters". They flowered at the same time, grew to the same height and were equally robust. Howard and Howard did not state which of these varieties was best suited for fiber production, but Youngberg (51) found the green-stemmed varieties to contain 4.75 percent more fiber than the red varieties.

In describing the type of plant grown in India and the material from which they selected the four varieties, Howard and Howard (25) stated that the height of the plants varied with the cultivation practice and in some cases reached ten feet. They gave the following botanical

TABLE 1

ECONOMIC VARIETIES OF *Hibiscus Sabdariffa*

Variety	*Use*	*Habit*	*Color*			
			Stem	*Leaf*	*Calyx*	*Corolla (withered)*
altissima (48) a[1].	fiber	tall,[2] unbranched	red	green with red veins	red	....
b[1].	fiber	tall, unbranched	green	green	green	....
c[1].	fiber	tall, unbranched	green, with red patches above and below leaf scars	green	green	pink
bhagalpuriensis (25)	fiber	short,[3] branched	green, with some diffused red color; red patch above leaf scars	green	bright green, with red splashes	orange-pink
intermedius (25)	fiber and fruit[4]	short, branched	green, with some diffused red color; red patch above and below leaf scars	green with some reddening on upper surface of veins	yellowish green; red spot on mid-nerve	yellow
albus (25)	fiber and fruit	short, branched	green	green	yellowish-green	yellow
ruber (25)	fiber and fruit	short, branched	dark red	green with red veins	red, gland on mid-nerve greenish	deep orange-pink
Archer (48)	fruit	short,[5] branched	green	green	green	....
Temprano (48)	fruit	short,[6] branched	light red	green with reddish veins	light red	....
Rico (47)	fruit	short, branched	dark red	green with reddish veins	dark red	....
Victor (45)	fruit	short, branched	reddish	green with reddish veins	reddish	....

[1] For convenience in this paper, the writer has divided the *altissima* variety into a, b and c types as indicated in this table.
[2] Sometimes exceeding 14 feet, depending upon soil and environmental conditions.
[3] Generally speaking, not exceeding seven feet.
[4] Enlarged edible calyces.
[5] Frequently exceeding 1.6 meters (5.2 feet).
[6] Rarely exceeding 1.25 meters (4.1 feet).

description of the species *Hibiscus Sabdariffa,* together with the major differences among the four varieties:

Shrub erect, annual. Stem glabrous, unarmed but with emergences at intervals, much branched with long branches arising near the base. Stipules generally simple and linear, sometimes bilobed. Leaves lobed, upper ones simple and lanceolate, with a pulvinus at the base of the blade, and a gland on the midrib of the leaf; margin serrate; petiole often with a line of hairs on the upper surface. Peduncle solitary and axillary. Epicalyx united at the base and adnate to the calyx; bracteoles 8–12, linear. Calyx connate below, free above; sepals 5–7, accrescent, fleshy, with a gland on the midnerve of each. Corolla yellow, spreading; aestivation imbricate. Capsules ovoid, pointed, villous, shorter than the calyx. Seeds reniform, subglabrous.

1. Var. *ruber*
   Stem and petiole entirely red, pulvinus red, calyx red, flowers on withering turn pink.
2. Var. *albus*
   Stem and petiole green, pulvinus green, calyx yellowish, flowers on withering remain yellow.
3. Var. *intermedius*
   Stem and petiole green with some red, pulvinus red, calyx yellowish green, flowers on withering remain yellow.
4. Var. *bhagalpuriensis*
   Stem and petiole green with some red, pulvinus green, calyx green with red splashes, slightly more obtuse and more twisted than in any of the other three varieties, flowers on withering turn pink.

Up to this point, all the varieties described belong to the type of *Hibiscus Sabdariffa* which is characterized by plants that are bushy and branch profusely, the branches arising from the base of the stem. Not until 1914 did Wester (48) describe the fiber-producing *H. Sabdariffa* var. *altissima.* This variety originated from seed received by the Philippine Bureau of Agriculture from the Gold Coast, West Africa, in 1911. Wester stated that the plant evidently had no economic value in the Gold Coast, for the correspondent forwarded the seed to him with the remark that it was an "interesting plant". Wester noted that plants grown from this seed "in some respects differ radically from all other forms examined by the writer. They differ from each other in that one kind belongs to the red type of roselle while the other form is intermediate between the red and the green".

A report (18) in 1912 states that botanical specimens of a species of *Hibiscus,* which had been grown in the Gold Coast, West Africa, for its fiber were forwarded to the Kew Botanical Gardens for identification. The specimens were identified as a variety of *H. Sabdariffa,* but were "not the form usually cultivated". Whether this plant material was the source of the seed from which Wester selected the variety *altissima* is not known. This tall unbranched form of *H. Sabdariffa* was, however, unheard of until after he named and described it in 1914.

In addition to the red and intermediate forms of the fiber variety *altissima,* there appears to be also a green-stemmed form, since Koch (28, 29), speaking of *altissima,* stated that "both red and green varieties grow 4 to 5 meters (13 to 16.5 feet) high with slender stalks and no branches". Although he may have overlooked the fact that the "green variety" might have contained small amounts of localized red pigments and, therefore, would be the intermediate form as described by Wester (48), Deshpande (12) and Abdur Rahman Kahn (2), a green form of the *altissima* type also seems likely to exist as it does in the shorter much-branched type of *Sabdariffa.*

From the obversations made by many students, the tall-growing variety *altissima* appears to be characterized by its non-branching growth habit (2, 12, 48) as contrasted with the other varieties which have a comparatively short and much branched growth habit (2, 45, 47, 48). Under certain conditions, however, the variety *altissima* has been observed to branch considerably. Some workers have observed that the variety branches somewhat when widely spaced or when growing next to drainage ditches or at the end of the rows (33, 43, pp. 48–49). Nevertheless, from the studies made on the plant by various workers, the conclusion may be drawn that the variety *altissima* can be given definite varietal rank.

Although nine varieties of *H. Sabdariffa* have been selected and named by Wester (45, 47, 48) and Howard and Howard (25), considerable synonymy is believed to exist in their varietal designations. For example, the culinary varieties Victor, Rico and Temprano, selected and named by Wester, are apparently synonymous with the variety *ruber,* named by the Howards. The Howards in 1911 were evidently not aware of the fact that Wester had named and described the culinary variety Victor in 1907, since they made no reference to this variety. Further, the belief is that the culinary variety Archer, a green-stemmed type selected by Wester, is the same as the green-stemmed variety *albus,* selected and named by the Howards.

Cytogenetics

In order to study the affinity of var. *altissima* with the varieties named by Howard and Howard (25), a number of intervarietal crosses were made (12). From this work strains were obtained combining the tall unbranched habit of var. *altissima* with the smooth stem of the other *Sabdariffa* types. Deshpande (12) crossed the *altissima* variety with varieties *albus* and *ruber* and also with some types of *H. cannabinus,* and showed that the average percentage of capsules set in the former was 53.8, all the capsules having viable seeds, whereas that in the latter was 44.4, none of the capsules having any viable seeds. These results are readily explained by the fact that, according to Medvedeva (34), the two species have different chromosome complements, *H. cannabinus* possessing 36 and *H. Sabdariffa* 72, respectively. He stated that all the crosses between the varieties and geographical races of *H. cannabinus* belong to the type of "congruent" crosses and are successful, but that, on the contrary, owing to the extreme diversity of karyotypes in the genus *Hibiscus,* the outlook of interspecific hybridization is not promising.

Anatomical Portion of the Plant Used for Fiber

The fibers obtained from roselle are spoken of botanically as "bast cells" and are 1.2 to 3.3 millimeters long and from 0.01 to 0.03 millimeter wide (35). They form the principal part of the fibrous bark, or the bast layer. These cells are contained in a layer just under the bark of the plant and outside the central woody cylinder and thin cambial tissue. Their ends overlap each other so as to form, in mass, a filament. Cells of this type give strength and flexibility to the stem, and the extracted bundles of these cells form the filamentous product known commercially as fiber.

Photoperiodic, Climatic and Soil Requirements

Roselle has been shown to exhibit marked photoperiodism (4, 27, 32). McClelland (32) found that, when the length of daily illumination was shortened to 11 hours, roselle plants developed buds four weeks after planting, produced large red fruit in ten weeks, although the plants were only five inches tall, and matured seed in 14 weeks. These plants remained about five inches tall. On the other hand, plants that were give a daily illumination of 13.5 hours for 5½ months attained a height of 36 to 45 inches, and none showed a tendency to blossom. These plants were still growing vigorously when those under the artificially shortened day, having fruited, were dying.

As roselle is sensitive to frost, subtropical or tropical locations seem to be the ideal environment for the plant. Because, regardless of the date of planting, the plant does not flower and fruit in the United States until the short days of late fall or early winter, production of roselle fruit in temperate zones seems difficult to achieve, unless frost-free conditions enable the plants to grow through December (27). For fiber production, on the other hand, it is highly desirable to have long clean stems free of branches or fruiting stalks which interrupt the continuity of the fiber. Plant material of this kind, therefore, may be obtained only when the plants have grown under comparatively long light days for three to four months. Since production of the finest quality fiber is dependent upon an environment that promotes continuous and rapid growth of the plant, 18 to 20 inches of rainfall during this three- to four-month period would seem to be desirable (6).

For fiber production the plants should not be subjected to strong winds or prolonged foggy weather, since the quality of the fiber is best when the plant is uninterrupted in its growth (6). It has been noted that a cessation of growth for only seven or eight days was sufficient to exert an unfavorable influence on the quantity and the quality of the fiber produced. Roselle appears to do equally well from locations at sea level to an elevation of 2,000 feet (38).

Roselle is not very exacting in its requirement with regard to the physical properties of the soil, except that it should be permeable, not very compact and not subject to flooding (6). In Ceylon (21) roselle has thrived on heavy loam soils capable of retaining a good supply of moisture. Laterite soils and light soils deficient in humus have proven to be unsuitable for satisfactory growth (22). In order to hasten maturity of the fruit, Beattie (3) recommends avoiding extremely rich soils or application of nitrogenous manures, since these stimulate development of large plants at the expense of flower production.

Cultural Requirements

The cultural requirements of roselle have not as yet been determined by extensive agronomic studies. Most of the information pertaining to the culture of this plant is based primarily on small plantings and limited observations by various individuals. One point, however, agreed upon by all writers is that preparation of the seedbed should be given special attention and the soil plowed rather deeply. Because of the comparatively long taproot of roselle, the soil should be plowed to such depths as to stimulate and aid the growth of these roots. The seedbed should be carefully prepared to aid in a uniform germination of the seed and subsequently a uniform stand of plants, which is of great importance in fiber-crop production. Not only is a uniform time of maturity desirable for the plants of a given area, so that they can be harvested and defibered at one time, but also desirable is uniform quality of the fiber.

Fertilization. A number of workers have studied the effects of application of fertilizers on the growth of roselle plants and the production of fruit and fiber. In the Philippines (39) it was found in all cases that such applications gave favorable effects on the height of plants irrespective of the fertilizer formulae used. Best results were obtained when nitrogen-bearing fertilizers were applied in combination with smaller amounts of potassium and phosphorus.

Ettling (15), Koch (29) and Dekker (11), all working in Java, pointed out that roselle was greatly benefited by the use of green-manure crops as a means of building up the soil preparatory to planting. They recommended the use of *Mimosa invisa* as a leguminous green-manure crop, provided it is turned under before it starts to mature its seeds. On the other hand, commercial fertilizers were also used with success, the greatest response being obtained from ammonium sulphate at the rate of 450 pounds per acre (11). These results are corroborated by the work in Africa and Java of Campese (6) who observed that nitrogen and potassium are the two elements that roselle needs in rather large quantities. He recommended application of manure at the rate of 8,000 to 18,000 pounds per acre or a commercial fertilizer supplemented with a green-manure crop.

Thus far no conclusive proof has been given as to whether a rotation of crops is necessary in growing roselle; but, since the plant is subject to attack by the root-knot nematode (*Heterodera radiciola*), a rotation is probably advisable (49). Campese (6) recommended that roselle be worked into a rotation program; that is, he suggested that it be preceded by a leguminous green-manure crop and followed by corn.

For fruit production Wester (45) stated that stable manure should be used sparingly and should be supplemented by phosphates and fertilizers containing potash. He found that an excess of ammonia in the soil encouraged the development of large plants at the expense of fruit production. A commercial 4-6-7 fertilizer gave good results, and he stated that best results were obtained in Florida when the organic forms of nitrogen were applied at the rate of 1,000 to 2,000 pounds per acre. Fertilizers in which inorganic sources of nitrogen were used did not give such high yields.

Time and Distance of Planting. The time of planting roselle, particularly for fiber, is one of the most important factors in its production. In view of the fact that the plant is sensitive to changes in length of day, it is readily understood that the best time for planting in a location of a given latitude might not be successful in another location of a different latitude. It is generally agreed (6, 28, 36) that roselle should be planted at the beginning of the rainy season. Likewise a daily illumination of approximately 13 hours for three to four months following planting is necessary in order to prevent flower bud initiation until after the plants reach sufficient height to insure adequate yields of fiber per area of land. In other words, in order to obtain long clean stems free of branches and fruiting stalks which interrupt the continuity of the fiber, planting should be done at the beginning of a three or four month period characterized by 18 to 20 inches of rainfall with day lengths of not less than 13 hours.

Experiments in Florida, Hawaii and the Philippines (47, 3) have shown that roselle normally begins blooming the latter part of September or the first of October. For fruit production, therefore, the seed may be sown any time after the first of February but before the middle of May in the Northern Hemisphere and before the corresponding time in the Southern. If planted later than the middle of May, the plants do not have sufficient time to develop vegetatively before flowering and fruiting begins.

Distance of planting is of great importance to the quality of fiber produced (15). Work in Java and Africa (6, 11, 15, 38) has shown that the best quality fiber is obtained from plants spaced six to 8 inches between rows and five to nine inches between plants in the row, using about 18 pounds of seed per acre. In Malay (22, 43), however, drilling in rows three to six inches apart at a rate of 20 to 25 pounds of seed per acre is recommended.

Broadcasting the seed has been tried in several instances, but this practice is not recommended because of the uneven stand of plants obtained and lack of uniformity in the fiber produced.

Since roselle is harvested for fiber when the plants begin to bloom, a separate planting for seed is necessary. At fiber-harvesting time the practice has been, in many places, to merely leave uncut a portion of the field as a source of seed. Harvesting seed from a planting originally intended for fiber, however, is difficult and costly. In addition, much lower yields of seed are obtained than from a planting made at the proper time and having a planting distance especially for seed production.

For the production of seed it is generally agreed that the distance between plants should be somewhat greater than for fiber production. In Java the planting distance varies from 30 inches between rows and 15 inches between plants to spacings of 30 to 40 inches on a square (11, 15). Similar treatment is recommended in Africa where plants are spaced 20 inches in the furrow with 32 inches between furrows (6).

For fruit production in the Philippine Islands (49), roselle is planted in hills 3 to 7½ feet apart with 4½ to 9 feet between rows, depending upon soil fertility, supply of moisture and the time of year when the seed is sown, the earlier sown seed being planted at the greater distances. In Florida (3) seedlings started indoors are re-planted in the open at the same time as tomatoes in rows four feet apart and from three to four feet apart in the row.

Recommendations regarding planting distances used in various parts of the world for fiber, seed and fruit production are summarized in Table 2.

TABLE 2

A SUMMARY OF DIFFERENT PLANTING RATES RECOMMENDED BY STUDENTS OF ROSELLE PRODUCTION

Author	*Country*	*Distance between rows*	*Distance between plants*	*Seed required per acre*
		Inches	*Inches*	*Pounds*
For fiber				
Koch (28)	Java	12	4 to 5	.
Ettling (15)	Java	6 to 8	5 to 9	18
Henning (22)	Malay	3[1]		25
Serdang Exp. Plant. (43)	Malay	3[1] to 6	. .	20 to 25
Campese (6)	Africa and Java	8	6	14 to 16
Dekker (11)	Java	6 to 8	6 to 8	19 to 23
Prat (38)	Africa	5 to 9	6 to 8	13 to 18
For seed				
Ettling (15)	Java	30	15	. .
Campese (6)	Africa and Java	31	20	
Dekker (11)	Java	30 to 40	30 to 40	.8 to 1.6
For fruit				
Wester (49)	Philippines	4.5[2] to 9	3[2] to 7.5	. .
Beattie (3)	Florida	4[2]	3[2] to 4	....

[1] Drilled.

[2] Feet.

Methods and Time of Harvesting. Roselle is such a rank grower that it soon shades out weed competition. Generally plantings made for fiber production require no cultivation or other care from the time of seeding to harvest. For seed and fruit production, where the rows are spaced farther apart, one or two cultivations may be necessary, depending upon seed bed preparation and weed population.

Some diversity of opinion exists as to the proper time for harvesting roselle for fiber. The recommended harvesting time has varied from the stage at which the plants first started to bloom until seed maturity. The results obtained by workers in Java and Malay (11, 43) indicate that the best time for harvesting is at the end of three or four months or "before large flowers have appeared". Henning (22), on the other hand, affirms that the best time for cutting is just after the plants have flowered. Other workers have observed that if harvesting is delayed until after blooming, the plants become woody, the fiber is of poor quality, and the stems are much more difficult to ret (6, 22).

As far as yield of fiber is concerned, the longer the plants are allowed to grow, the greater is the quantity of fiber obtained per unit of area. Michotte (36) presents the following data from Java, which clearly illustrate this point:

TABLE 3

RELATION BETWEEN DURATION OF GROWTH AND FIBER YIELD IN ROSELLE

Plants cut after	*Yield in dry fiber, pounds per acre*
100 days growth	1,338
135 days growth	2,230
165 days growth	2,677

Even though a progressive increase in yield of fiber is obtained with a progressive increase in length of time that the plants remain in the field, Campese (6) noted that there was a progressive decrease in quality of the fiber produced. He stated that the plants should be cut between three and four months after planting to obtain the best quality fiber.

There appear to be two methods of harvesting the plants. They may be pulled up by the roots or cut off at the ground level. The latter method seems preferable in that it requires less effort, and the root systems remaining in the ground constitute a source of organic matter.

Some authors (15, 25, 33) have declared that the cut stalks should be tied in bundles of 25 to 30 preparatory to retting; others (22, 28, 43) have asserted that a more economical and satisfactory way is to strip off the cortex in the field and tie it in bundles for retting.

The slow and tedious process of harvesting roselle by hand in this hemisphere is impractical and uneconomical because of comparatively high wage rates. Since the habit of growth and size of the roselle plant are similar to those of kenaf, mechanical harvesters used for harvesting the latter plant should undoubtedly prove successful for roselle. Harvesting investigations on a commercial scale, using a modified hemp harvester-binder, have demonstrated that a crop of kenaf planted in eight-inch drills rows, which had grown to a height of 10 to 12 feet, could be cut and bundled at the rate of an acre per hour (10).

The seed capsules of roselle mature progressively from the lower to the upper portion of the plant. For seed production the plants are cut when the seeds at the lower and middle portion of the bearing area are fully mature. The common method of harvesting roselle for seed is to cut the plants by hand at the stage just mentioned and to shock them in the field for several days, so that seed at the top portion will have time to mature and cure before threshing. If harvesting by hand is delayed until all the seed capsules on the plant have reached maturity, then considerable seed is lost by shattering, especially from the lower portion of the seed-bearing area. To thresh roselle, the dried plants have usually been placed between large pieces of canvas and then beaten or flailed with long poles, after which the seed has been cleaned by winnowing. Here again, if this crop is to become of commercial importance in this hemisphere, mechanical methods for harvesting and cleaning seed will have to be developed.

The edible fleshy calyces mature very

rapidly and are ready to harvest within 15 days after blossoming (49). The fruit is gathered when the calyces are plump, crisp and of a deep red color, and before any woody matter has formed (3). If the calyces are picked promptly after attaining full size, the plants continue to bloom longer, the harvest is prolonged and the yield is materially increased.

Fiber Extraction

There are various means of extracting the fiber from roselle stalks, all of which involve retting in water, except when power-driven decorticating machines are used. No consistent agreement was found in the literature on the best retting procedure for roselle but, generally speaking, most workers (11, 22, 43) agree that the stalks are sufficiently retted after 8 to 10 days. The work of Campese (6) and experiments in the Philippines (1) showed that the fiber can not be washed until after 14 or 15 days, and Wester (45) held that the material should be retted for 15 to 20 days. Horst (24) reported that freshly cut stalks required 21 days to ret, whereas partially dried stalks retted well in 15 days.

The variation in the length of the retting period, as reported in the literature, is caused, no doubt, by the greatly divergent environmental conditions under which the plants were grown, the differing stages of maturity of the plants at the time of harvesting, the different kinds (fresh, stagnant, *etc.*) and temperatures of the retting water used, and the many other differing inter-relationships that were not controlled or considered.

The retting process is complete when the bark separates easily from the central woody cylinder and the fiber washes clean. At this stage the bundles of stalks are broken open and the fiber is stripped and cleaned by hand, after which it is dried in the sun. A skilled worker can strip 80 to 100 pounds of dry clean fiber in a day.

Extraction by mechanical means apparently has not received attention, since there is no reference to the subject in the literature. The similarity between the roselle plant and the kenaf plant, as discussed above, would indicate that roselle might also be defibered successfully by machine. Large henequen—(*Agave fourcroydes* Lem.)—decorticating machines have been used in Cuba to process kenaf (10). These machines scrape away the central woody cylinder, water and waste material from the stalks, leaving the clean fiber which is then dried in the sun.

Yields. The yield of dried fiber per unit of area, as reported in the literature, varied widely according to the soil and climatic conditions where the crop was grown. The percentage of extracted fiber from the stalks ranged from 2.3 percent (28) to 7.9 percent (50). In general, the average yield per acre seemed to be about 1,500 pounds of dried fiber. In West Africa (18), yields of 600 pounds per acre were reported; in Ceylon (7), 1,970 pounds per acre; Dekker (11), in Java, reported yields of approximately 1,338 pounds per acre, while Michotte (36) reported yields in British Malay ranging from 1,115 to 3,123 pounds per acre.

The only reference in the literature regarding seed yield is that of Campese (6). He reported that an acre of roselle cultivated for seed produced only 357 pounds of seed, enough to plant about 18 acres for the production of fiber if seeded at the rate of 20 pounds per acre.

Wester (49) stated that 5,000 to 7,000 pounds of roselle calyces may be obtained per acre from plantings made during May. He noted that with good varieties and under favorable conditions these yields may be nearly doubled. Data from Hawaii (49) bear out this fact in that, grown as an intercrop with rubber, roselle yielded 15,000 pounds of fruit per acre. In Florida the yield varies with the region and conditions of growth, but may be anywhere from three to 12 or 15 pounds per plant (3).

Uses and Properties of Roselle

Fiber. As to the utility and quality of roselle fiber, there is considerable disagreement among the various authors reporting on the subject. This, however, is to be expected, since the conditions under which the plants were grown and the methods of preparing the fiber differed greatly. Campese (6) maintains that well-prepared roselle fiber can be woven into bed clothing, table linen and other articles for which cotton is used. The fiber is twice as strong as jute, and ropes and cables made of roselle, according to him, were preferred by the "navy and merchant marine" because they deteriorated little when wet and did not rot if left for a long time in salt or fresh water. Fishing nets made from this fiber, he said, were also extremely resistant and broke only under great strain. He stated that fiber from young plants is suitable for the manufacture of paper. Ettling (15) and Prat (38), discussing the characteristics of roselle fiber, state that it is twice as strong as jute, is very resistant to sea water, and can be spun without difficulty.

Of a sample of *Hibiscus Sabdariffa* fiber from the Gold Coast, West Africa (18), the Imperial Institute in London made a chemical analysis and presented the following data in comparison with extra fine jute fiber. The fiber was stated to be of good strength and had an average length of about 5.5 feet, though it had been imperfectly prepared. From these data it was concluded that roselle fiber is somewhat inferior in chemical composition and behavior to jute fiber, since it lost more on hydrolysis and contained less cellulose.

Frenzl and Bruggencate (16) found in a study of the spinning and weaving qualities of roselle fiber from Java that it was not inferior in strength to first-class jute fiber. They also found that the color was better than that of first-class Calcutta jute, and that the flexibility was less than in jute. The spinning and weaving of roselle fiber with the methods in use for jute gave some difficulty. Cloth made from roselle yarn appeared good, but because of the lower flexibility, the cloth and yarn were not so strong as that made from jute. They concluded that sugar bags made from roselle fiber would be usable in the Dutch sugar factories, but that the fiber would not be suitable in tapestry. Lack of flexibility was the only fault that Oudot (37) and Spoon (42) found with sacks made from the fiber.

TABLE 4
COMPARISON OF ROSELLE AND JUTE FIBER

	Hibiscus Sabdariffa	*Extra fine Indian jute*
	%	%
Moisture	8.9	9.6
Ash	1.1	0.7
a hydrolysis, loss	12.3	9.1
b hydrolysis, loss	17.8	13.1
Acid purification, loss	1.5	2.0
Cellulose	73.9	77.7
Length of bast cells	0.08 to 0.16 in.	0.06 to 0.12 in.

Other Plant Parts. Howard and Howard (25), discussing the uses of roselle, stated: "Almost every part of the plant can be utilized. The stems yield a strong silky fibre known to commerce as 'Rozelle Hemp'. The fleshy calyces, which have a pleasant acid taste, and a very attractive red color are extensively used in jellies, chutnies and preserves. In the West Indies a cooling drink is also prepared from them. The seeds are useful in medicine and the leaves are employed for salads and curries".

The calyces of the edible varieties of *Hibiscus Sabdariffa* can be made into a sauce, similar to cranberry (*Vaccinium macrocarpon* Ait.) in color and flavor, which can be used as a filler for shortcakes and pies (49). The calyces can be used in the manufacture of jelly, sirup, flavoring extracts and wine. Similar products may be made from the tender leaves and stems, and resemble the preparations made from the calyces except that the color is less brilliant. Because of the similarity in the uses and flavor of roselle products to those of cranberry products, a comparison of their analyses is of interest (49). The following of roselle were made on the calyx after the refuse, which is about 50 percent of the weight of the calyx, consisting of the seed pod and the stem end of the calyx, had been cut away:

TABLE 5

ANALYSIS OF ROSELLE CALYX AFTER SEPARATION FROM SEED POD AND STEM

Constituents	*Roselle grown in the Philippines*	*Roselle grown in Florida*	*Cranberry*
	%	%	%
Water	82.49	88.91	88.53
Solids	17.51	11.09	11.47
Ash	1.26	0.89	0.25
Marc (insoluble matter)	7.39	6.67	4.60
Acid (as malic)	3.31	2.77	2.74
Reducing sugar as invert	0.82	0.33	1.90
Sucrose	0.24	0.03	0.10
Benzoic acid	Absent	Absent	Present

Heath (20) stated that quince juice was often combined with roselle juice in jelly-making and that the roots contain saponin. Watt (44) asserted that the fleshy calyx is a valuable antiscorbutic, and is much eaten in the form of jellies, chutneys and preserves in India. The leaves have been consumed there as a salad and in native curries, and the seeds have been employed in medicine because of their demulcent, diuretic and tonic properties. Cook and Collins (8) stated that the calyces may be preserved by drying and in this condition were sometimes found in tropical markets. Leupin (30) told of a drug called "karkade" that was obtained from the red-stalked varieties, the contents of which were oxalic, malic, citric and tartaric acids.

Dunstan (14) reported the nutrient value of roselle seeds as somewhat higher than that of linseed or cottonseed cake, and said this was due to the large percentage of fat they contained. The seeds were lower, however, in albuminoids and contained little or no starch. The amount of indigestible matter or crude fiber present was particularly large, and, on account of this fact and the hard nature of the seed coat, the value of the material as a feeding stuff for cattle was considerably diminished. Dunstan remarked that the natives of northern Nigeria ground the seed into a coarse meal and used it as a food.

Georgi (17) found that *Hibiscus Sabdariffa* var. *altissima* seed contains about 17 percent of an oil which is very similar to both kapok and cotton seed oils and can doubtless be used for the same purpose as these oils.

Summary

Roselle, *Hibiscus Sabdariffa*, belongs to the family Malvaceae. It is an annual plant that is grown for its bast fibers and its edible calyces and leaves. There are several varieties, some of which are of a tall, comparatively unbranched type, suitable for fiber production, and others are of a shorter, much-branched type, cultivated, generally, for their edible calyces. Both types, on the basis of color characteristics, have been divided into three groups: plants of which the stems are red, plants of which the stems are green, and plants intermediate between the red- and green-stemmed types. Varietal names, based primarily on color differences, especially in the short, much-branched type of plant, have been given to the two groups differing in growth habit.

Although roselle appears to be adapted to wide variations in climatic and soil conditions, a well-drained sandy loam soil with a considerable quantity of humus appears to best meet the requirements of the plant. From six to ten inches of rainfall per month for three to four months is essential for the successful production of roselle fiber. Likewise the length of the daily light period during the time when the crop is grown should be approximately 13 hours or greater in order to prevent flower bud initiation and subsequent blossoming until after the plants have reached a sufficient height to insure profitable yields of fiber. Similar environmental requirements are essential for the production of roselle fruit (calyces). The growing season should be five to six months long, accompanied by day lengths of less than 13 hours during the latter part of this period to promote blossoming and subsequent fruit production.

Planting may be done by broadcasting, seeding in rows or drilling, but the last method seems to be preferred for fiber production. The optimum planting distance is dependent upon soil fertility and related factors, but, generally speaking, for fiber production a distance of from four to eight inches between plants in rows six to twelve inches apart has been used. Planting distances for seed or fruit production are considerably increased. Weed competition during the early part of the growing season should be kept at a minimum.

Upon harvesting, the plants are either pulled up by the roots or cut off at ground level. The stalks are tied in bundles and retted in water, or the cortex may be stripped from the stalks in the field, tied in bundles and retted. Generally retting is complete in from eight to ten days. The fiber is then removed, washed and dried. The yield of dried fiber varies from 1,000 to 2,000 pounds per acre, depending upon soil, environmental conditions and other factors. Fruit yield may reach as high as 15,000 pounds per acre.

Roselle fiber may be employed in the manufacture of sacking material, ropes and cordage of all kinds, fishing nets and articles for which jute fiber is used. The enlarged fleshy calyces seem to offer an excellent substitute for cranberries and may be used as a filler for shortcakes and pies, and in the manufacture of jelly, sirup and flavoring extracts. Roselle seed contains about 17 percent of an oil which is similar to both kapok and cotton seed oils.

If roselle is to become a commercially important crop in this hemisphere, mechanical methods of planting, harvesting and fiber extraction will have to be developed. Mechanical methods now used in the production of kenaf seem adaptable.

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Essential Oils. When Old-World sources of essential oils, on which consumers of those oils in the U. S. A. have been to a very large extent dependent, were cut off by World War II, numerous attempts were made in North, Central and South America to produce the same oils or others that might take their places. Many important economic and technical considerations, discussed in this article, were overlooked by would-be producers in seeking these replacements.

In the U. S. A., for instance, because of high labor costs, essential oils can be successfully produced commercially only as by-products, for example, citrus oils, or only when the plants can be cultivated and harvested by machinery, as in the production of the peppermint and dill oils of the West. For the same labor cost reasons, attempts to produce eucalyptus oils on a large scale in California had to be forsaken. Commercial use of wild plant material in the U. S. A. is likewise limited. Native wintergreen oil [*Gaultheria procumbens*] and sweet birch oil [*Betula lenta*] have attained some importance, and among the newer oils from wild plants is that of wild carrot, or Queen Ann's lace [*Daucus Carota*]. The American product is distilled from the whole herb, whereas the French carrot oil is obtained only from the seed.

In California an essential oil has been produced on a small scale from the mountain laurel, or California bay tree (*Umbellularia californica*), which is not to be confused with commercial laurel-leaf oil distilled from *Laurus nobilis*. The California oil has an annual consumption in the U. S. A. of perhaps only 100 pounds, and utilization of greater quantities by conversion of the umbellulone in the oil through hydrogenation into thymol must compete with already established large scale production of thymol from parcymene, a very cheap starting material.

Ocimum oils and the oil from the wild American sage, *Artemisia tridentata*, contain large amounts of natural camphor, "but the cost of the camphor separated from the oils is higher than that of the synthetic product manufactured from pinene obtained from turpentine".

Vetiver oil, distilled from the roots of very old wild plants [*Vetiveria zizanioides*] in Haiti, was accepted in the trade only when the war cut off the supply of better oil from the roots of highly cultivated plants, usually not more than two years old, in Réunion and Java. The American oil has continued to be in demand since it was once accepted, and production of it in Haiti is increasing.

Other attempts to produce essential oils that have been commercially unsuccessful because of economic and technological difficulties, include patchouly [*Pogostemon Cablin*] in the Western Hemisphere, sweet basil oil (*Ocimum Basilicum*) in Haiti, lavender oil [*Lavandula officinalis*] in the State of Washington, and ylang ylang [*Canangia odorata*] in Honduras.

Despite the foregoing and other difficulties associated with the development of new sources of essential oils, the following new ones for the Western Hemisphere show promise of commercial success:

I. South American Oils

OIL OF *OCOTEA PRETIOSA* or OIL OF *OCOTEA CYMBARUM*:—Formerly known as "Brazilian sassafras oil". About 200 tons produced annually in Brazil. Contains about 90% safrole, an important isolate and intermediate for isosafrole and heliotropin, both important perfume and flavoring ingredients. "The unavailability, due to the war, of the usual source of safrole (namely, Formosan, Japanese and Chinese camphor oil fractions) caused the immediate acceptance of this Brazilian product".

OIL OF *MENTHA ARVENSIS*:—Brazilian production has decreased from about 2,000 tons in 1945 to about 150 tons in 1947. "Substantial quantities of this oil have been produced in Brazil, primarily for the isolation of natural *l*-menthol of U. S. P. quality. Neither the oil nor the dementholized oil can be used as a pharmaceutical in the United States because the official U. S. P. oil must be distilled from *Mentha piperita*. Importation is permitted only under affidavit", and its use must be other than as a pharmaceutical.

OIL OF SWEET ORANGE [*Citrus*

sinensis]:—Brazilian production has decreased from about 120 tons in 1926 to about 40 tons in 1947, but "has eased the situation caused by the temporary disappearance of sweet orange oil from French Guinea".

OIL OF MANDARIN [*Citrus nobilis* var. *deliciosa*]:—About 1,000 kilograms produced annually in Brazil. The oil was accepted in the trade when Italian imports were suspended. It differs from the Italian product in being machine-pressed instead of hand-pressed and in being deep green instead of yellow.

OIL OF *EUCALYPTUS* — Cineole type [*Eucalyptus globulus*]: — Potential production is very great, since many hundreds of thousands of trees have been planted in South America, but "competition with the long established Australian oils will prove difficult".

OIL OF *EUCALYPTUS CITRIODORA*: —Ten to 12 tons produced annually in Brazil. "This oil contains the aldehyde, citronellal, as its main constituent. Large quantities of citronellal are used in this country for conversion into hydroxy-citronellal and into synthetic menthol."

OIL OF CABREUVA [*Myrocarpus frondosus*]. Production figures are unavailable, but in 1946 more than 700 kg. were exported from Santos alone. "The oil has excellent fixative properties, and has the very soft odor characteristic of a sesquiterpene alcohol. Whether or not it will win a permanent place in commerce is still uncertain and will depend primarily upon the price of the oil."

II. Central American Oils

OIL OF CITRONELLA [*Cymbopogon Nardus*]:—About 200 tons produced annually at present in Guatemala, Honduras and Haiti where this plant has been successfully introduced. The oil is well established in commerce today in competition with that from Java.

OIL OF LEMONGRASS [*Cymbopogon citratus*]:—About 30 tons produced annually in Guatemala and Honduras in competition with oil from the East Indies. "This oil is an important source for the aldehyde, citral, useful in flavors and also as an intermediate for the production of the ionones".

OIL OF *EUCALYPTUS STAIGERIANA*.—A few hundred pounds produced annually. "In addition to citral, the oil appears to contain geranyl acetate and geraniol, resulting in a very pleasant fruity, lemon-like odor and flavor."

OIL OF CORIANDER [*Coriandrum sativum*]:—Very small quantities produced in Guatemala, and commercial acceptance still uncertain.

III. West Indian Oils

OIL OF NEROLI:—Production in Haiti very variable, but up to 1,000 pounds could be produced annually if necessary. "It is distilled from the flowers of a variety of orange (probably the bitter-sweet) different from that cultivated in Europe. The flowers are collected from semiwild and wild-growing trees which have escaped from cultivation long ago. Besides, the plant material is not carefully selected and is often admixed with flowers from the shaddock, parent plant of the American grapefruit. The odor is quite different from the oil neroli bigarade produced in France".

OIL OF PETITGRAIN:—[From the leaves and twigs of both bitter and sweet oranges]. About ten tons produced annually in Haiti.

OIL OF VETIVER:—About ten tons produced annually in Haiti. "The Haitian oil is distilled from the very old roots of semi-wild growing plants [*Vetiveria zizanioides*]. Although the odor differs somewhat from the Java and Réunion types, the oil has been accepted by the trade".

OIL OF LEMONGRASS:—About ten tons produced annually.

IV. North American Oils

OIL OF TANGERINE:—Up to ten tons could be produced annually in Florida if the demand warranted. "This oil is obtained as a by-product from the canning of tangerine juice. Substantial quantities are potentially available. The oil cannot replace any of the other citrus oils. The Florida tangerine oil apparently contains no methyl ester of N-methyl anthranilic acid, or if this ester is present, it occurs in traces only. Hence the oil is very different from mandarin oil. The trade has not generally accepted this oil as yet. Recent samples extracted in new types of juice and peel presses had a much improved odor and flavor, approaching the true character of the tangerine peel".

OIL OF LEMONGRASS:—No production in Florida at present. "Lemongrass was planted as a supplementary crop by a sugar cane grower. After distillation of the oil, the exhausted plant material was mixed with molasses residues and used as a cattle food. Production of this oil has recently been discontinued for economic reasons".

OIL OF CEDARWOOD:—Large potential production in Texas. "This oil is distilled from *Juniperus mexicana* Schiede, and not from the *Juniperus virginiana* L., the source of the cedarwood oils of the South. The two oils are quite similar in composition, but the new Texas product appears to have a somewhat harsher odor. Analytically, the main difference observed is the much greater laevorotation of the Texas product. Large quantities of oil can be made available if the demand should warrant it". *(E. S. Guenther & E. E. Langenau, Proc. Sci. Sect., The Toilet Goods Assoc., Nov. 8, Dec. 1947).*

Cannery Residues. Cannery residue wastes in the United States, amounting to thousands of tons annually, have been found to contain "sugars, oils, pectins, waxes, proteins, tannins, acids, enzymes and a variety of other organic compounds". These are contained in the waste pits of apricots, peaches, prunes, olives and cherries; the shells of walnuts, filberts and almonds; seeds of apples, tomatoes, grapes, citrus fruits and melons; leafy and butt trimmings; fruit skins, cores and trimmings; peels and rinds of melon and citrus fruits; pomace from juice factories and wineries; stems, pods, hulls, cobs, husks and vines.

If the technological and economic problems associated with recovering these materials can be solved, there are great possibilities for new byproducts industries. Investigations toward this end have been pursued by many Federal, State and private agencies. The results of these studies so far have shown, among other things, that:

a) Leafy wastes, more so than stem wastes, from beets, spinach, broccoli, carrots, cabbage, cauliflower, kale, lima beans, peas, rutabagas, tomatoes and turnips contain a rich supply of carotene, riboflavin and protein.

b) Broccoli meal is nutritionally better than commercially produced alfalfa meal for poultry feed supplement, and meal from turnip and carrot tops is as good as alfalfa meal.

c) Lima bean wastes, pea vines, pea pods and asparagus butts may be found to yield valuable meal, either alone or in mixture with alfalfa.

d) Asparagus-waste juice is of use in culturing *Bacillus subtilis* to produce the antibiotic subtilin.

e) "Corncobs, oat hulls, cottonseed hulls, flax shives, peanut shells, and rice husks are being utilized by the duPont Company to manufacture a key intermediate product for nylon. A new million dollar plant at Niagara Falls, New York, was built by duPont to study further this problem of utilization".

f) "The Western Regional Research Laboratory has recently developed a new protective coating for meat and other products, made from citrus peel, apple pomace and vegetable waste products. A soluble pectinate, treated chemically, forms a gel or film to provide a very strong protective film. This film will dissolve when the product it covers is boiled and it may be left on and eaten as it is tender and edible".

g) Fermentation of pear waste—45% of the raw product—might yield alcohol, vitamin-B, glycerol, acetone, butyl alcohol, amyl alcohol, manite, pyruvic acid, yeast, syrup and vinegar. In 1947 there were 96,000 tons of waste from pears.

h) Apple peels and cores have been used for syrup; a syrup from concentrated apple juice has been used by one cigarette manufacturer to replace glycerin; and apple waste is the source of manufactured pectin and wax.

i) "Three products—ursolic acid, cranberry wax and oil—have been produced on a limited scale to utilize cranberry wastes. The acid might well be an excellent ingredient for cosmetics and has already proven to be a good water-in-oil emulsifying agent. It has been said that a cream prepared from the wax and ursolic acid is an excellent medicine for burns".

j) Apricot, peach and cherry pits yield a refined sweet oil suitable for cooking, pharmaceuticals, cosmetics and packing sardines. "Bitter almond oil, recovered from sweet oil press cake, may be used as a medicinal without further treatment. Apricot kernels provide the source of practically all the macaroon paste used by bakers. Ground apricot and peach pits may be used as dynamite base, wood flour for plastics or for the preparation of absorbent charcoals. Acetic acid, acetone and charcoal are products of whole peach pits which have been dried". (*E. H. Wiegand, Chemurgic Digest* 7(1): 9. 1948).

Peanuts in Africa. As one measure of meeting the world-wide shortage in fats and oils, the British Government, in December, 1946, adopted a "Report of a Mission to Investigate the Practicability of the Mass Production of Groundnuts in East and Central Africa". This report recommended the establishment of 107 mechanized units, each of 30,000 acres extent and all totaling nearly 3¼ million acres (over 5,000 square miles), 80 of the units for Tanganyika Territory, 17 for Northern Rhodesia and 10 for Kenya. This ambitious project, involving enormous expenditures and problems in introducing mechanized farming to unoccupied agricultural land, was regarded as capable of producing 50,000 tons of groundnuts, or peanuts, in 1948, and a maximum of 400,000 tons by 1951. Combatting malaria and sleeping sickness is only one of the problems involved, and eventually, it is estimated, 100,000 people will be engaged in the undertaking. The first crop was gathered in May, 1948, from 7,500 acres planted in December, 1947.

"To the average consumer of peanut butter, salted peanuts, or peanut candy (the three widest uses in the United States) the food has no great significance beyond its agreeable taste. Few realize, for instance, that peanuts are one of the six basic food crops in the United States, that peanut production in the United States is worth three times that of rye, or that as a cash crop, in the State of Georgia, peanuts are a close runner-up to cotton.

"Nobody was much interested in cultivating peanuts in the United States until the first years of this century when the arrival of the boll weevil from Mexico compelled Southern farmers to turn some of their attention from cotton to peanuts. In 1909, around 550,000 acres of peanuts were picked and threshed. By the middle years of World War II this figure had increased seven times.

"In 1938 the United States was still far from being a leading exporter of peanuts. India, producer of nearly three-quarters of the quantity that entered into world trade, led the list. Senegal, China, Japan and Nigeria furnished the next largest amounts. The biggest importers were France, Britain, Germany and the Netherlands, countries which processed the nuts and then (except for Germany) were the largest exporters of peanut oil.

"The war brought many changes in production and export patterns. India, the leading pre-war exporter, sent out none in 1946. British East and West Africa (including Nigeria) jumpted into first place, followed by French West and Equatorial Africa (including Senegal). China and Japan dropped right out of the picture, leaving the United States in third place, although her exports were not high. The continent of Africa is today supplying most of the word exports of peanuts and peanut oil". (*Not Just Peanuts. Publ. by British Information Services, 1948*).

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VOL. 3 APRIL–JUNE, 1949 No. 2

Semi-Popular Articles

A CHEMURGIC SURVEY OF THE DESERT FLORA IN THE AMERICAN SOUTHWEST. *Robert E. Cruse* . . . 111

PRODUCTION, IN VENEZUELA, OF INDIGENOUS VARIETIES OF TOBACCO. *Frederick A. Wolf* . . . 132

THE "PALO DE TOMATE" OR TREE TOMATO. *E. P. Hume and H. F. Winters* . . . 140

SAFFLOWER. *Carl E. Claassen* . . . 143

CINCHONA CULTIVATION IN GUATEMALA—A BRIEF HISTORICAL REVIEW UP TO 1943. *Wilson Popenoe* . . . 150

THE AMERICAN PEANUT INDUSTRY. *C. Lewis Wrenshall* . . . 158

PRODUCTION AND UTILIZATION OF ALFALFA. *Francis P. Griffiths* . . 170

MICROBIAL FARMING. *H. C. Yin* . . . 184

Technical Literature Review

WATERMELON BREEDING. *G. K. Parris* . . . 193

Utilization Abstracts

By the Editor

Page 131—Jojoba. *Page 139*—Yerba Maté. *Page 142*—Chlorophyll. *Page 149*—Drug Plants of Africa. *Page 157*—Vegetable Oils of Venezuela. *Page 169*—Pecan By-products. *Page 192*—Hardwood Pulp. *Page 213*—Chemurgic Utilization of Wood. *Page 215*—Hyoscine and Hyoscyamine. *Page 216*—Cocona. *Page 217*—*Cedarwood Oil.* *Page 219*—Wormwood. Cottonseed.

A Chemurgic Survey of the Desert Flora in the American Southwest

While commercial utilization of the desert flora in the American Southwest is still scarcely begun, there are possibilities of obtaining stock feed, alcohol, paper pulp, sugars, starches, resins, gums, alkaloids, oils and other extractives from the xerophytic plants of the region.

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Introduction

The semi-arid lands of the Southwest stand out as one of the largest undeveloped regions of the United States. There are approximately 100,000 square miles in this area covering Arizona, Nevada, southern New Mexico, and parts of Texas and California. The mean annual rainfall is 15 inches or less. The flora of the region is unique and consists largely of cacti and other xerophytic vegetation which up to the present time have been of little commercial use and serve mainly as a part of the landscape arousing the admiration of passing tourists.

The need for domestic and replenishable sources of many raw materials has been amply emphasized by World War II. It is hoped that this article may serve to extend the horizons of possibilities in this direction, by presenting a survey of past investigations and of work now in progress on the utilization of various plants of the American Southwest and northern Mexico. Attempts to utilize these plants heretofore have been limited, primarily because of the economic factors involved.

Stock Feed

The utilization of desert plants for stock feed is perhaps the most promising possibility. A large part of the region serves as a grazing range for livestock, especially cattle, and it is not surprising that this field was investigated as early as 1907 (35, 36). At that time cacti were shown to compare favorably with ordinary green fodders and root crops. Ash analysis showed large amounts of calcium, magnesium and potash.

One of the most recent experiments was carried out in 1945 by Valley Vitamins, Inc., a subsidiary of Godfrey L. Cabot, Inc., in their vitamin-A plant at McAllen, Texas. A half-ton of prickly pear cactus was dehydrated and showed a protein content between 7 and 8 per cent. Corn has a protein content of slightly over 10 per cent. According to Mr. L. M. Salmon, manager of the plant, research on the prickly pear will be continued.

Patents have been granted on various methods of processing cacti for stock feed, including incorporation of the crushed plant into cottonseed meal (33) and digestion of the cacti in their own juices to render all parts edible, including the spines (9).

Yucca, too, has been considered as a

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stock feed. Analysis yields, on a dry weight basis, 4.4% protein, 6.7% ash, 1.5% fat, 3.2% fiber, 49.2% carbohydrates. Yucca may yield 1,000–2,000 lbs. of green plant per acre (4).

Sarcobatus vermiculatus (Hook.) Torrey, the common greasewood, is undesirable as a stock feed because of its oxalate content, even though no alkaloids, glucosides, saponins, cyanates or similar compounds are present. The oxalates are present as the sodium and potassium salts in the ratio of 4:1 (21).

Alcohol

The various species of cacti contain a large amount of fermentable sugars, or starches and carbohydrates which can be converted to fermentable sugars. Alcohol is obtainable from these sugars by conventional fermentation methods. The cacti are digested in water under slight pressure at 120° to 135° C., the formic acid formed is blown off, and the liquid is fermented with yeast and ammonium phosphate (62, 63). With prickly pear cacti the plant pulp is adjusted to 4%–14% acidity with tartaric acid. After fermentation the crude beer contains about 9.2% ethanol by volume (44).

It is interesting to note that in certain kinds of cacti, ethanol and acetaldehyde are present in the fresh plant in small amounts. Concentration of these increases somewhat in the absence of oxygen (37). Attempts have also been made to hydrolyze mesquite wood (*Prosopis* spp.) fiber for the production of alcohol.

Species of *Agave* have been used many years in the production of a fermented liquor called "pulque". When this liquor is distilled the potent mescal—called "tequila" in some parts of Mexico—is produced. Commercial ethanol production from *Agave* has not been attempted, so far as is known, because pulque and mescal production takes the entire supply of raw material.

Paper and Cellulose

Several of the desert plants, notably yucca (*Yucca* spp.) and sisal, contain long strong cellulose fibers which are excellent for making heavy kraft paper. One such paper, which is commercially available, exhibits unusually high tearing resistance. It is quite resistant to wear and has been used as flashing and weatherstripping material in house construction, and for other uses requiring a tough paper. The fibers have also been used in making burlap and bagging, and those of some species could be used for cordage.

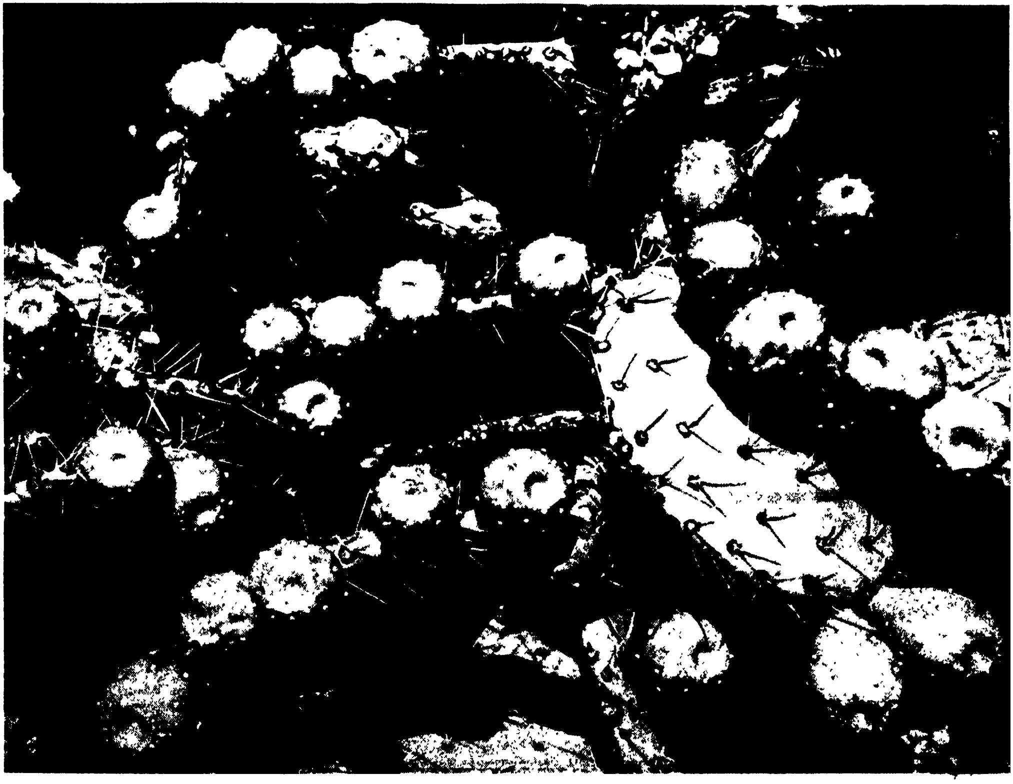
Possibly the most important of these species is *Yucca glauca* Fraser, colloquially known as "bear grass" or "soapweed". A large acreage of this plant grows in the area under consideration. During World War II a considerable amount of it was shipped to a paper mill near the Pacific Coast where the fiber was extracted and made, for the use of the Navy, into the type of paper mentioned above.

In harvesting *Y. glauca* and similar flexible leaved species, such as *Y. elata* Eng., the practically stemless plants are cut at the ground and allowed to dry in the field. This requires about two weeks, after which the plants are gathered somewhat like hay, hauled to a central location and compressed into 300-pound bales which yield over 100 pounds of paper pulp.

It has been found that the fiber from

FIG. 1 (*Upper*). Guayule, *Parthenium argentatum*, one of the recognized secondary sources of rubber that have been exploited to some extent.

FIG. 2 (*Lower*). Prickly pear, *Opuntia Engelmanii*, the flat stems of which offer a possible commercial source of stock feed in the Southwest. The large but poorly flavored edible fruit is rarely eaten, even by the Indians. (*Courtesy of Esther Henderson, Tucson, Arizona*).



rigid-leaved (bayonet) yuccas is over 30 per cent stronger than the fiber from the flexible-leaved species and has but slightly less tensile strength than Manila, the strongest rope fiber. The tensile strength of Manila is rated as 62 kilometers, or about 38 miles, long before it will break under its own weight. In comparison the fiber from species of rigid-leaved yuccas varies from 54 to 61

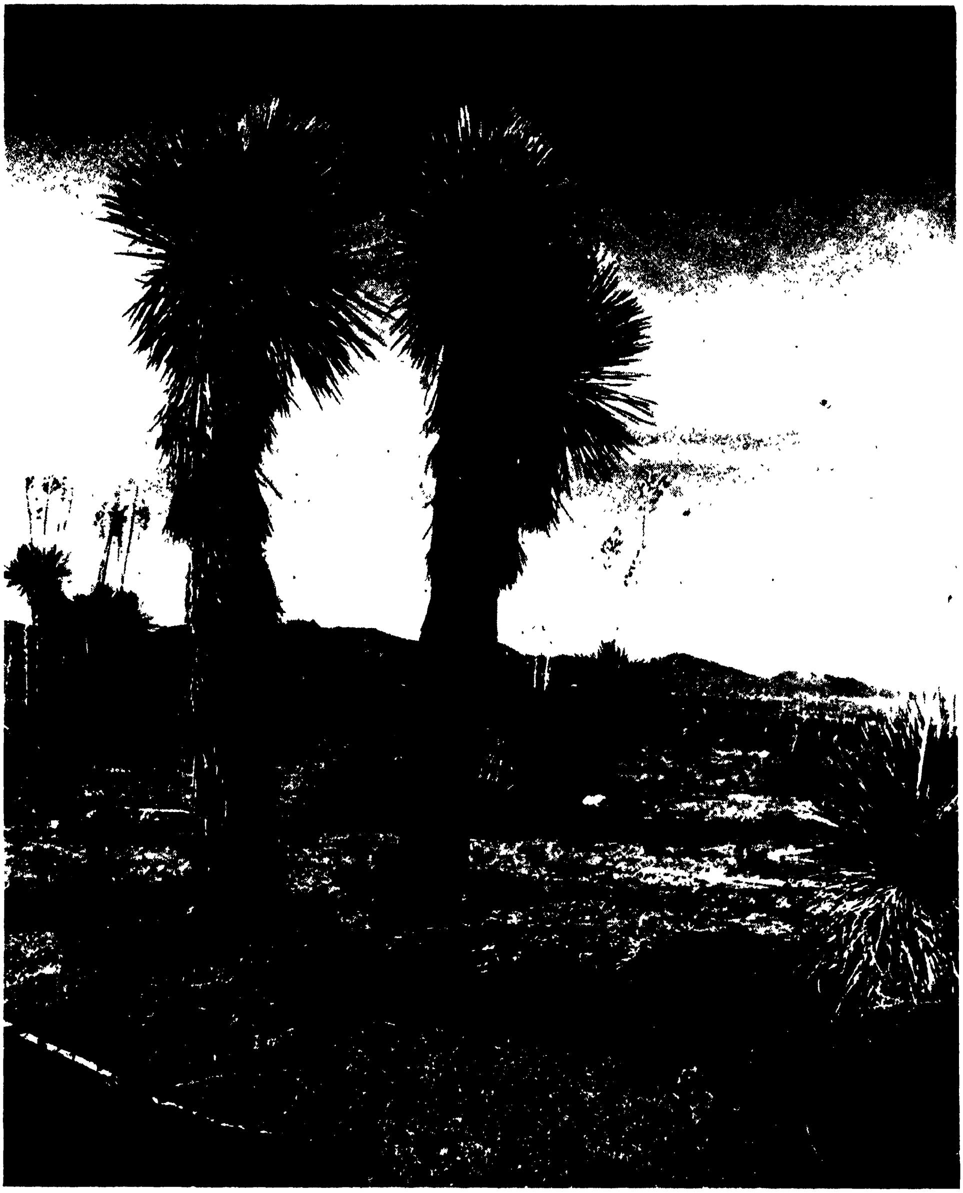


FIG. 3. *Yucca baccata* in southeastern Arizona. The fibers of this and other species of *Yucca* have been the subject of considerable technical and patent literature in connection with their use in paper-pulp. (*Courtesy of Western Ways*).

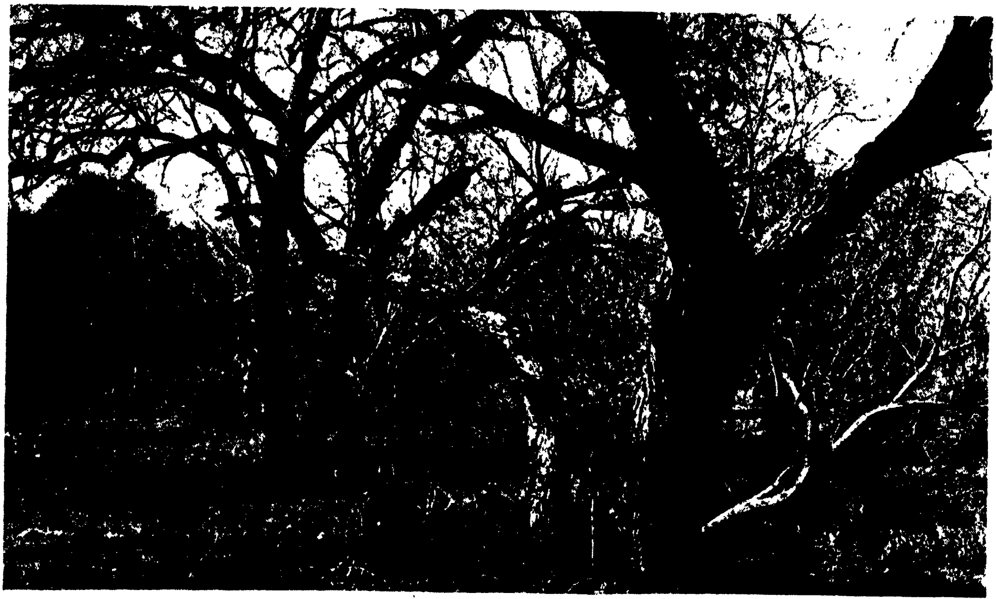
kilometers, while that of steel is less than ten. Therefore, for equal weights of material, these natural fibers are approximately six times as strong as steel. However, since steel is more dense, it is stronger for an equal cross section. According to Botkin (13), if the stockpile of Manila fiber had not been large in 1941, the Navy probably would have utilized yucca fiber for rope in addition to their use of the flexible leaf fiber for paper. Although yucca fibers are known to be a desirable raw material, active harvesting programs have been sporadic because only the wild plants have been used. The Government built a $250,000 plant at Kingman, Arizona, to extract the fiber, but production was small and the plant is no longer in operation.

The preparation and use of yucca and similar fibers for paper-making has been the subject of considerable technical and patent literature. The basic process involves digestion of the raw fibers with caustic (57) or caustic and alum (41), washing and drying. Various modifications, especially in the machinery used, are claimed to improve both yield and quality of the fiber obtained (15, 20, 56, 61). Chemical variations include digestion of the fibers in solutions of zinc sulfate (45) and sodium carbonate (19). Much of the work on yucca has been of German origin (19, 20, 67), and there are surveys (11, 53) of the work in Germany. The German yucca fibers appear to be similar to those of the North American plant. The latter has been surveyed in Mexico (23) and in New Mexico (12). The entire subject of the utilization of desert plant fibers has also been reviewed (13).

A small amount of work has been done on the cacti. The Sardinian cactus (*Opuntia ficus-indica* L.), treated with electrolytic alkali hypochlorite at ordinary temperature, gave a completely white and relatively pure lignin-free cellulose with yields of 35%–41%. The alpha-cellulose content was 76%–81% (24). This work was probably done on the entire plant, including both the pulp and the woody skeleton. Apparently some value is placed on the skeleton alone as a source of fiber-like material (1). Reference is made only to the process of loosening the pulp from the skeleton with steam and then removing the pulp mechanically.

Another plant for which potentially new uses might be found is *Nolina Texana* Watson, or "Sacahuiste". This plant, which grows abundantly in parts of New Mexico, is edible but cannot be classed as an important feed. In fact, cattle eat the grass to the ground around *Nolina* clumps, evading the coarse rough leaves of the plant. *Nolina* grows in large bunches. The leaves, which are from two to five feet long and less than one-half inch wide, are high in cellulose and contain about 48% of crude fiber. They have been used in the making of long, rather stiff brooms for street cleaning, and apparently would be satisfactory for baskets and mats. The plants are harvested by cutting at the base, and after drying are tied in bundles with the roots at the same end of the bundle. In this condition, according to Botkin (13), *Nolina* may bring 40 dollars per ton at the baler. Here the ends are trimmed so as to make 18–24-inch lengths before being baled in a broom-corn baler. The native supply is much in excess of the broom requirement, and, since the leaves are high in cellulose, it is hoped that other uses may be found for this material.

Pulp and paper research on mesquite wood is being planned by the Texas Forest Service (45*a*). Studies of first priority will probably involve use of a digester and wet lap machine with the thought that this type of small localized pulp industry will be of most practical application to the region. The wet lap



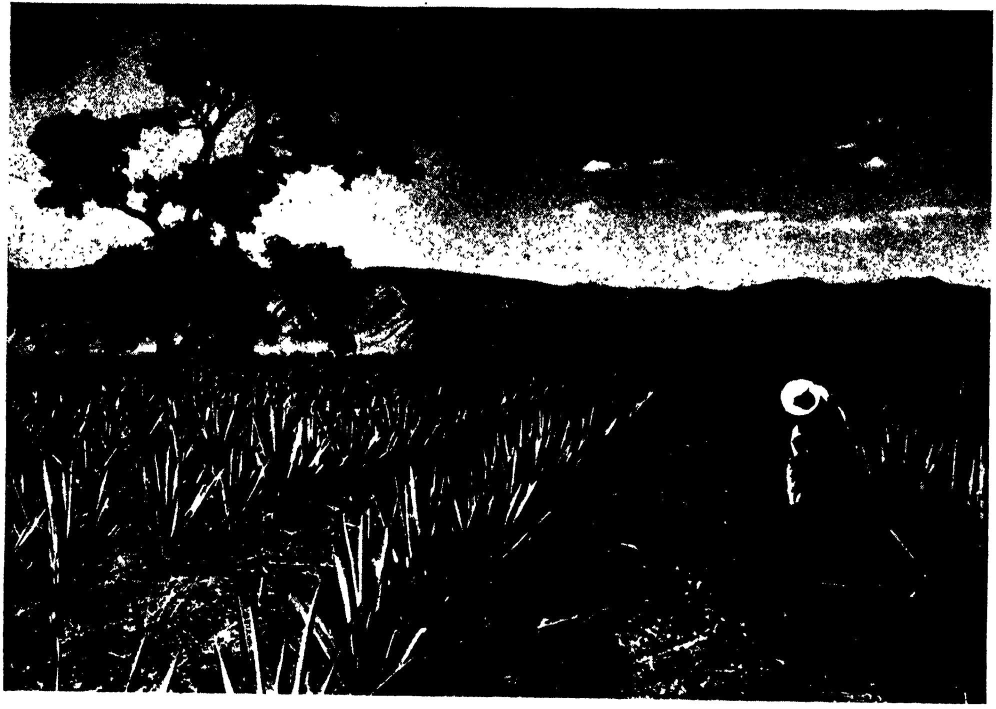
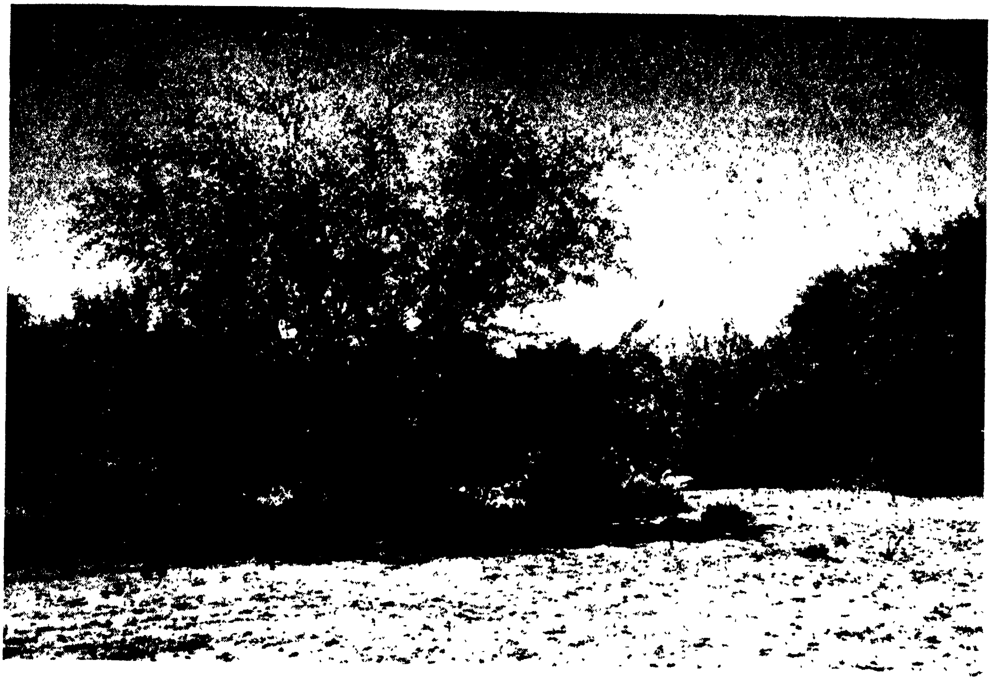


FIG. 4 (*Upper*). November scene in a mesquite grove of Texas. (*Courtesy of Texas Forest Service*).

FIG. 5 (*Lower*). *Agave* sp. under cultivation in Jalisco, Mexico, for fermentation into the potent beverage pulque which is imbibed as such by the natives or is distilled into equally intoxicating mescal, or tequila. (*Courtesy of Western Ways*).



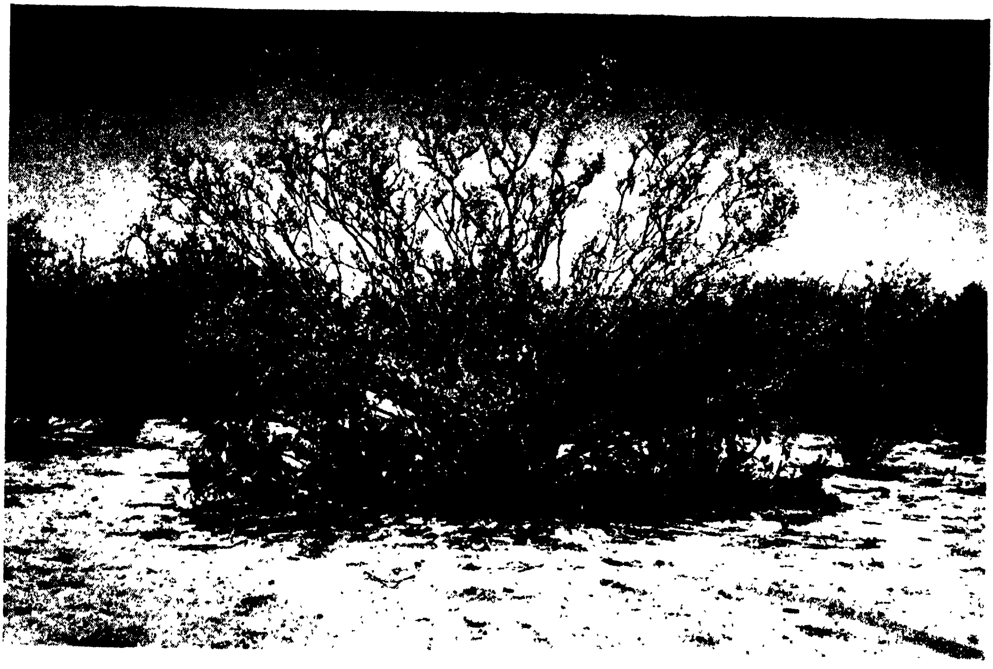


FIG. 6 (*Upper*). Mesquite, *Prosopis juliflora* DC., near Tucson, Arizona. The pods of this and other species of *Prosopis* are used as food by Indians and Mexicans, and gum of commercial value is exuded on the stems. (*Courtesy of Western Ways*).

FIG. 7 (*Lower*). Creosote bush, *Larrea tridentata* (DC) Cov., a possible commercial source of resins. (*Courtesy of Western Ways*).

pulp could then be shipped to a large centrally located mill for fabrication and treatment.

Sugars and Starches

Starches of the type of cornstarch or other domestic grain starches either have not been found or have not been investigated in the various cacti and desert plants. An extended investigation on the gums of mesquite and cholla revealed that *l*-arabinose, *d*-galactose, *l*-rhamnose and glucuronic acids make up the major part of the gum structure (2, 3, 54). Each fraction is capable of being isolated by acid hydrolysis. Fructose, fructosans, dilevans and glucose are present in several species of *Yucca* (26, 55). The beans of the mesquite contain pentosans, galactans and other carbohydrates, while the bean pods are rich in sucrose. Spoehr (60) has presented a summary of the types of sugar in the cacti.

Resins and Gums

Several species of the desert plants under discussion yield resinous gums. In an investigation (3) of mesquite gum emphasis was on the sugars obtainable from the gum, rather than on any use of the gum as such. Diaz (25) distilled mesquite gum and obtained a wax which appears to have possibilities as a replacement or substitute for gum arabic.

Cholla gum from *Opuntia fulgida* Eng., was found to be insoluble in the usual organic solvents, but was soluble in aqueous ammonia or alkali (10). Hydrolysis with 4% aqueous sulfuric acid yielded glucose and pentosans. Other species of *Opuntia*, especially the prickly pear varieties, yield a mucilage which can be used advantageously as an adhesive material in Bordeaux mixture, Paris green and similar sprays in aqueous suspension (29). The performance of DDT and other insecticides might possibly be improved by addition of this mucilage to the spray.

The U. S. Rubber Co. has recently investigated the extraction of resins from the creosote bush (*Larrea tridentata* (DC.) Cov.) at San Simon, Arizona. Several drugstores in the region of Tucson, Arizona, sell mesquite and cholla gum for various uses, but the business is mostly local.

Pharmaceutical Products

"Peyote" is the colloquial name for a group of cacti in the genus *Lophophra*, especially *L. Williamsii* (Lem.) Coult. These grayish-green spineless cacti grow on both banks of the Rio Grande, and in Mexico as far south as Hidalgo. They are rather insignificant in appearance, and the greater part of each plant consists of root. The alkaloids of peyote, or mezcal (mescal), are localized in the internal cells of the cortical parenchyma of the top or crown of the plant. The crowns, cut off and dried, form small discs called "mezcal buttons" which when eaten cause a peculiar type of intoxication; the plant is therefore sometimes called "dry whiskey". One of the alkaloids is capable of producing indescribably beautiful colored hallucinations which occur along with increased respiration, hypertension, muscular incoordination, and in some cases convulsions. No mental disturbances are produced, however.

Havelock Ellis gives the following description of the visions that came to him while under the influence of peyote. "Every color and tone conceivable to me appeared at some time or another. . . . At first there was merely a vague play of light and shade which suggested pictures, but never made them. Then the pictures became more definite, but too confused and crowded to be described, beyond saying that they were of the same general character as the images of the kaleidoscope: symmetrical groupings of spiked objects. Then, in the course of the evening, they became distinct, but still indescribable—mostly a vast field of golden jewels, studded with red and green stones, ever changing. At the same time, the air around me seemed to be flushed with vague perfume, produc-

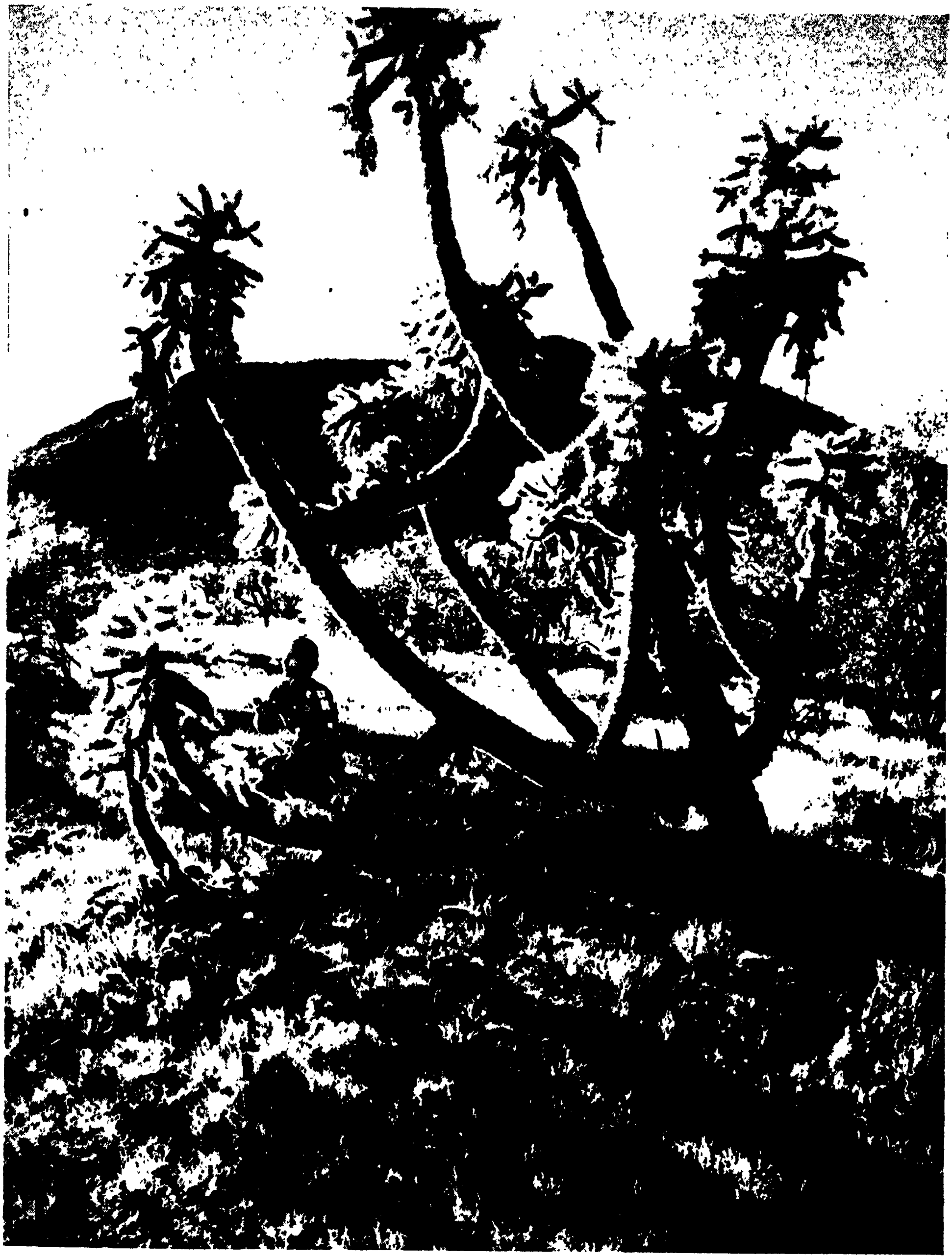


Fig. 8. *Opuntia fulgida,* the common cholla of Arizona, from which a gum of possible industrial value can be obtained. (*Courtesy of Esther Henderson, Tucson, Arizona*).

ing with the visions a delicious effect, and all discomfort had vanished except a slight faintness and tremor of the hands''.

Intoxication from peyote is singular in that consciousness is never lost, control of the limbs is maintained, a feeling of well-being is experienced, no urge to commit any act of violence is induced, and rarely are there uncomfortable after-effects. The question as to whether peyote is habit-forming is still unsettled, but observations tend to suggest that it is not. The Indians do not use it habitually but only on occasions of ceremony and as a therapeutic agent. They consider it as the greatest of medicines.

When the Spaniards came to Mexico they found that the peyote was worshipped by the natives. In spite of four centuries of civil and religious opposition this worship has not died out in Mexico among the Indians; in fact, circumstances attendant upon the spread of white man's culture throughout North America have made it possible for the peyote religion of Mexico to diffuse in a modified form to more than 30 Indian tribes of the United States.

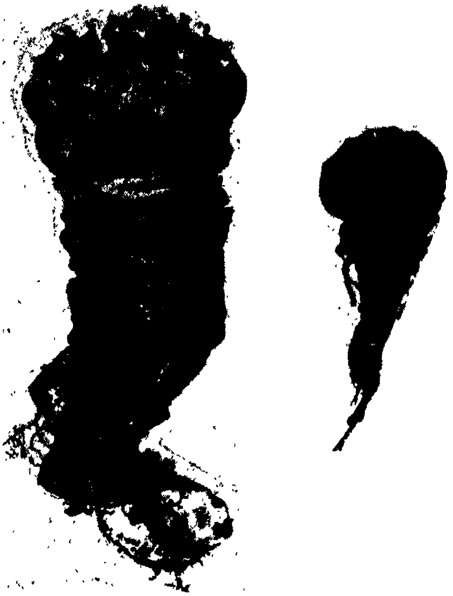


FIG. 9. Peyote, *Lophophora Williamsii* (Lem.) Coult. These small, grayish-green, spineless cacti are mostly root, but their crowns, when cut off and dried, form ''mescal buttons'' which contain powerful narcotic alkaloids and provide the basis of worship by certain Indian tribes of the Southwest. (*Courtesy of Nature Magazine*).

FIG. 10. The crown of peyote which, when cut off and dried, constitutes ''mescal buttons'', the alkaloids of which have a molecular structure based on B-phenyl ethylamine. (*Courtesy of Nature Magazine*).

Many tribes, far removed from the home of peyote, are supplied by merchants on the Rio Grande in Texas, and a large trade has grown up in mezcal buttons. However, no attempt has been made to cultivate peyote, so far as is known, either for its intoxicating effect or for extraction of its alkaloids. Many of these alkaloids have been found to have a molecular structure based on the beta-phenyl ethylamine skeleton. The latter is also the skeleton for the adrenal and sympathomimetic drugs. Spath and his associates (59) at the University of Vienna extensively investigated the anhalonium alkaloids obtained from a Mexican species of peyote, *Echinocactus Lewinii* Hennings (Syn. *Mammillaria Williamsii* Coulter), and named them anhalamine, anhaline, anhalinine, anhalonidine, anhalonine, lophophorine, mezcaline, N-acetylmezcaline, N-methyl mescaline, O-methyl-d-anhalonidine and pellotine.

Spath's work covered the fundamental research and structure proof of these compounds, but did not offer any applications, medicinally or otherwise. The various isoquinoline structures may be regarded as cylicized N-alkyl-beta phenyl ethyl amine derivatives.

From the Sahuaro cactus (*Cereus* (*Carnegica*) *gigantea* Enge.) an alkaloid was isolated (38), and Roca obtained three others from the Mexican cactus *Pachycereus marginatus*, (DC) B & R.—cereine, pachycereine, ochoterenine. No further work has been reported on this investigation since Roça's initial paper in 1931. In South America Du Cloux (28) investigated the cactus species *Tricocereus* sp. aff. *T. Terschecki*, and found it to contain an alkaloid having malic acid as the main acid principle, but no phenolic groups, which seem to be so prevalent with the anhalonium-type alkaloids. The fresh plant of *Trichocereus candicans* (Gillies) B & R, containing 95% water, was found to have on this wet basis, 0.05% each of anhaline and a quatenary anhalonium base (49).

The rayless goldenrod (*Aplopappus Hartwigi* (A. Gray) Blake) also contains alkaloids and pyridine (16), but again no use has been found for the extractives.

An unidentified alkaloid, resembling candicine and nicotine in physiological action, has been obtained from *Cereus coryne* Salm-Dyck, a large tree cactus (7). The material was thought possibly to be a dihydroxy phenyl triethyl ammonium compound. By extracting mezcal with 70% alcohol, peyotline, anhalonine and lophophorine are obtained, and can be isolated in the form of these hydrochlorides (64).

The pharmacological properties of cactus alkaloids have been studied by several investigators (*e.g.*, 14, 39, 43). The isoquinoline structure of some of these alkaloids indicates that with some modification of the attached groups, possibilities for antimalarials may exist.

Oils

The field of vegetable oils has been surveyed rather extensively. With the supply still short, new sources of oils have been sought, both for food and for industrial use. From the seeds of a species of *Opuntia*, an oil can be extracted to the extent of 6% by weight (50), the properties of which are listed in Table I. Upon saponification two acid fractions, one a solid and the other a liquid, were obtained. The properties of the saponified products are listed in Table II. Gourd seeds may also serve as a source of oil which may be hydrogenated into shortening (65). Three wild gourds grow in the Southwest, particularly in the desert, *Cucurbita foetidissima* HBK, *C. palmata* S. Watson, and *C. digitata* A. Gray. The seed of these gourds was used for food by the Indians of the region. The white man adopted such Indian foods as maize, squash, potatoes and beans, but curiously enough seeds from these gourds have been overlooked.

TABLE I

PROPERTIES OF PRICKLY PEAR SEED OIL

Density	0.9216
Index of Refraction	1.4744
Freezing Point	–10° C
Thermosulfuric Index	65°
Acid No.	5.26
Saponification No.	194.10
Acetyl No.	24.5
Acetyl Saponification No.	210.3
Iodine No.	125.20
Glycerol Assay	9.40%

These species are potentially of considerable agricultural and commercial importance for the following reasons: they are perennial and have large fleshy

TABLE II

PROPERTIES OF THE ACID FRACTIONS OF SAPONIFIED PRICKLY PEAR SEED OIL

	Solid Fraction	*Liquid Fraction*
Per Cent of the Total Oil	13.3	73.35
Melting Point	58° C	..
Freezing Point	50° C	−8° C
Index of Refraction	1.4626 (55° C)	1.4760 (15° C)
Acid No.	13.30	195.30
Iodine No.	18.5	143.40

roots which serve as storage organs for food and moisture; they grow wild on waste lands in regions of low rainfall; they produce an abundant crop of fruit which contains seed rich in oil and protein; the fruit lends itself to mechanical harvesting; and the flesh dries so completely that the seed can be threshed.

Each fruit contains about 12 grams of seed, and, estimating 60 fruits to the plant and approximately 1,200 plants to the acre, an acre could produce 1,800 pounds of seed. From an analysis conducted at the Connecticut Agricultural Experiment Station, the seed of *Cucurbita foetidissima* contained 33.95% fat and 34.22% protein. These calculated yields compare very favorably with other oil- and protein-bearing crops, such as soybeans and peanuts.

No experimentation on these gourds has yet been made in the United States, and it is not known how the oil and the pressed cake containing the protein will compare with other oils and proteins as a food for men and livestock. However, oil from cultivated cucurbits is prized for cooking in the Balkan countries, and squash seeds are relished as food in many parts of the world.

There grows in eastern Mexico, a small tree, *Garcia nutans* Rohr., which bears capsules containing three seeds, each approximately one-half inch in diameter. These seeds analyze about 55 percent oil which has an iodine number of 177 and is superior in some respects to tung oil. Since the stand of the tree is small, test plantings in Texas and Florida have been made to determine the possibilities of the tree on a plantation basis.

Of equal interest is the jojoba (*Simmondsia chinensis* Californica Nuttall), a shrub native to northwestern Mexico and southern Arizona. Although its roasted seeds are eaten by the Indians, and cattle forage for the plant, investigation as to its commercial use is only in an initial stage. The seeds contain approximately 50% of liquid wax, currently a substitute for waxes formerly imported to make shoe polish and other products. Of even more significance are reports that this liquid wax has a constant viscosity over a wide range of temperatures. This is a source of vegetable lubricating oil similar to sperm oil. In yield tests, as much as 14 pounds of seeds have been secured annually from a plant. The adaptability of the species is being tested in Texas. In Arizona 600 acres have been planted by Durkee Famous Foods, a division of the Glidden Company.

Miscellaneous Extractives and Products

Saponin ($C_{24}H_{40}O_{14}$) has been extracted from the roots of *Yucca filamentosa* Wood (17). The extract has been advertised for sale, and the plants are now being cultivated near Willcox, Arizona, for further exploitation. Saponin has also been obtained from cacti by a process involving the use of diatomaceous earth (48). Canaigre (*Rumex hymenosepalus* Torrey), a member of the dock family, has roots yielding about 25% tannin (4). Tyrosinase of great potency and tyrosine have been found in the Mexican cactus *Pachycereus marginatus* (DC) B & R. (52).

In progress at the present time is an investigation of the various desert plants as sources of odoriferous aldehydes, essential oils and perfume materials. The work is under the direction of T. F. Buehrer of the University of Arizona.

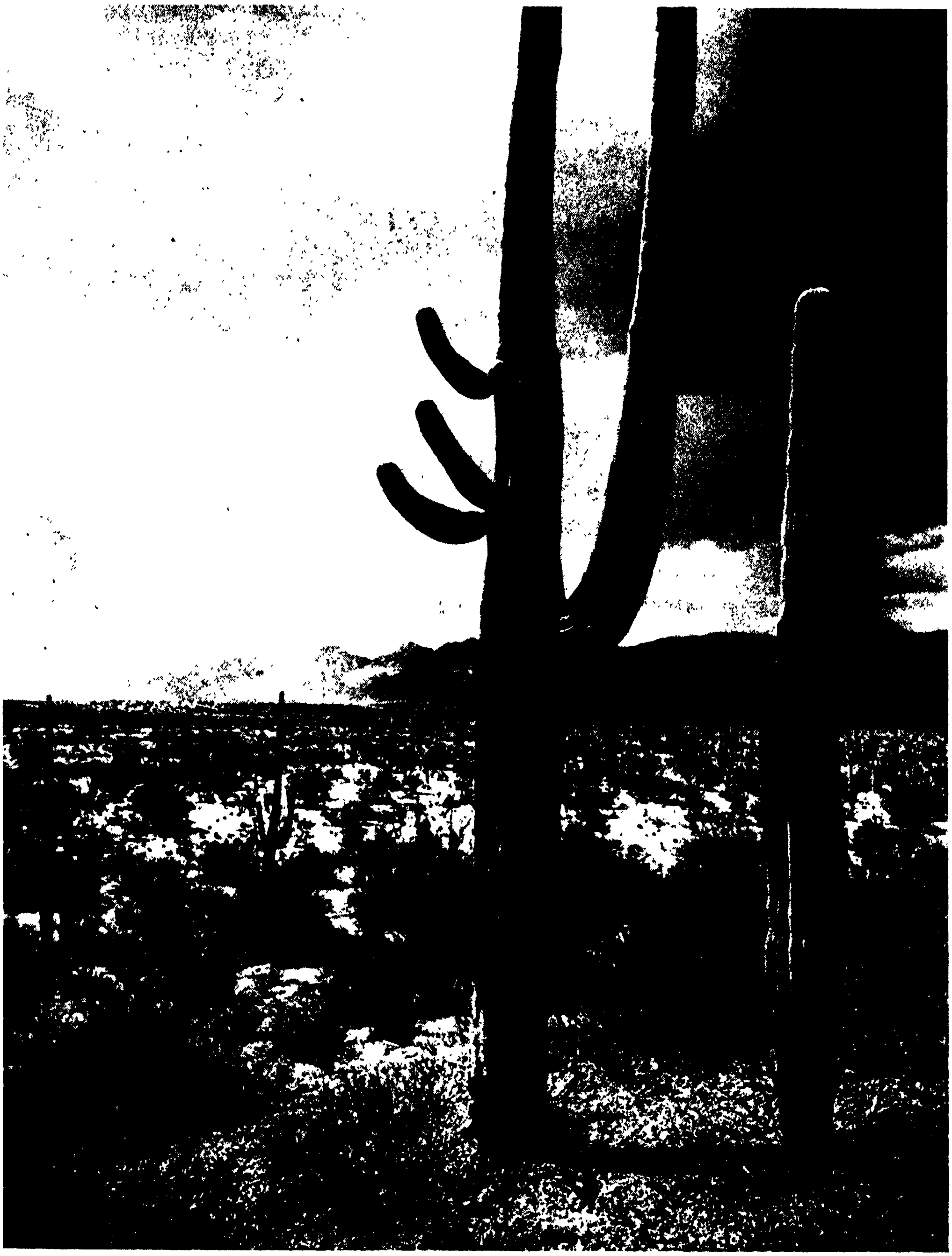
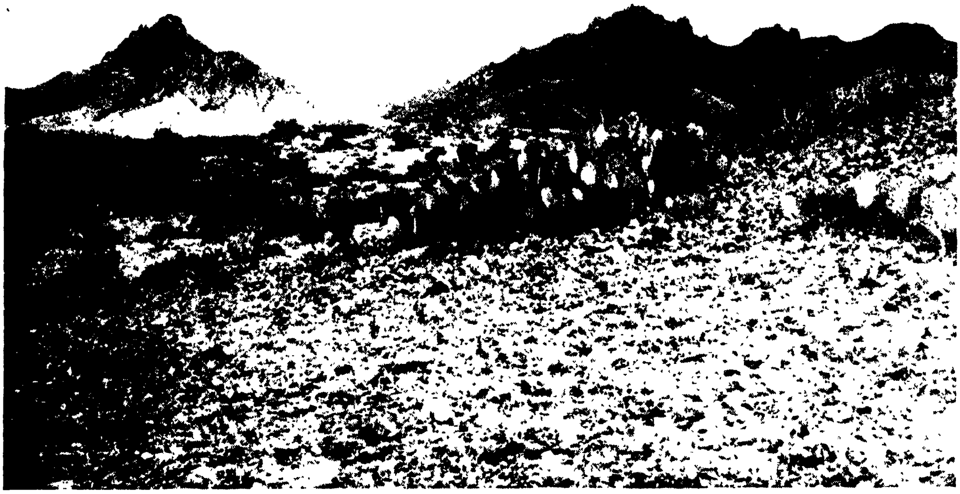


FIG. 11. Sahuara, *Carnegeia gigantea*, the giant tree cactus of the Southwest. The fruit was once used by the Indians for making a palatable syrup to be eaten as such or to be fermented into wine and vinegar. Alkaloids in the plant may have industrial value. (*Courtesy of Esther Henderson, Tucson, Arizona*).

Aldehydes, apparently of an essential oil type, have been obtained by fermentation of cactus pulp and subsequent hydrolysis and distillation (58).

In many parts of the region under consideration the mesquite (*Prosopis juliflora* DC) is a predominant part of the desert flora. It is an aggressive plant, and in the past hundred years, presumably chiefly due to overgrazing and grass fires, has invaded areas as far north as western Oklahoma. Because of its in-



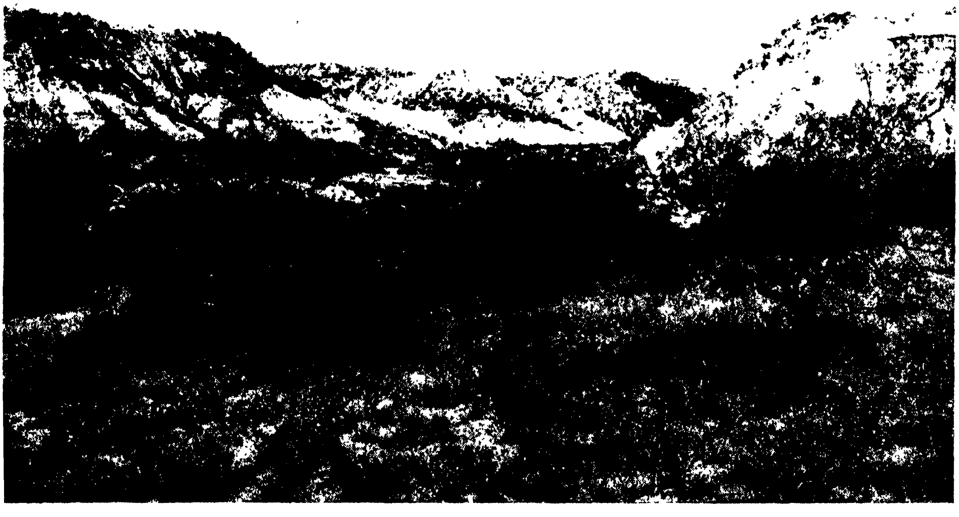


FIG. 12 (*Upper*). Vegetation in the Chisos Mountains of Texas, consisting of prickly pear cactus, *Opuntia* sp.; lechuquilla, *Agave Lecheguilla*; and creosote bush, *Larrea tridentata*. (*Courtesy of the Texas Forest Service*).

FIG. 13 (*Lower*). Mesquite, *Prosopis* sp.; and cedar brush, *Juniperus* sp. along one of the forks of Palo Duro Canyon in Texas. (*Courtesy of the Texas Forest Service*).

vasion of grasslands it has been estimated to cost the ranchers of Texas alone over $30,000,000 each year in lost income (45*a*). Therefore, utilization of mesquite would have a twofold purpose. Present utilization is mainly for fence posts and fuel, and a limited amount of finished lumber and other products has been produced. A small amount of mesquite charcoal is made in Mexico and sold in the United States. However, no large commercial utilization is being practiced, and, although research on uses of mesquite is being conducted, it has not advanced to the point where definite operations can be recommended. Marshall (45*a*) suggests the following possibilities for research on the utilization of the various species: destructive distillation for charcoal, distillate and activated carbon; wood hydrolysis for stock feed, sugars, alcohol and acids; pulp and paper; hydrogenation; tannin extraction; special wood products; plastics; gum; properties and uses of leaves, pods, roots and bark.

The Texas Forest Service Laboratory is studying destructive distillation of mesquite. Preliminary studies on the hydrolysis of mesquite wood have not shown much promise, principally because the wood is relatively low in cellulose content (45 per cent) and because the great amount of inert material absorbs some of the sugar that should be obtained. Mesquite wood yields about 28 gallons of 95 per cent ethyl alcohol per ton of wood. Southern yellow pine, for comparison, yields 49 gallons.

As has been mentioned, pulp and paper research on mesquite wood is to be carried out by the same laboratories.

Hydrogenation of mesquite is another field of research that has not been touched. However, from hydrogenation on other woods it is reasonable to assume that products such as mixed phenols and methyl alcohol might be obtained commercially from mesquite.

The relatively low yield of tannin from mesquite (5%–9% of the heartwood, 5% of the bark) will probably prohibit profitable commercial extraction of tannin in itself. However, if profitable uses could be found for spent chips—such as plastics, wallboard—then commercial production of tannin might prove profitable.

The color and grain of mesquite wood are similar to those of mahogany. The wood is hard, finishes well and has low shrinkage. Its chief disadvantage is its brittleness and the fact that it is oftentimes cross-grained. Its use has been suggested for flooring, paving blocks and cabinet shop products. Paving blocks of mesquite have withstood 25 years of use in a street in San Santonio, Texas (45*a*).

The use of mesquite for plastics seems to hold promise. Mesquite flour has been used as a filler with phenol-formaldehyde resins to produce a desirable plastic. Partial hydrolysis of mesquite with use of the residue for ligno-cellulose plastics is a possibility. The relatively low percentage of cellulose and high percentage of lignin react in favor of mesquite for this type of plastic.

Although mesquite gum has been collected in the past and has been sold locally, no large-scale collection is taking place at present, so far as is known. Its possible use has already been discussed.

A dye (a fustic substitute, algarrobin) has been found in a variety of mesquite, *Prosopis algarrobilla* Griseb. (46). The same author (47) also mentions the occurrence in mesquite of another dye, khaki yellow in color. The wood, bark and pods of mesquite contain tannin in addition to the above dye. The fruit has been analyzed and the seeds found to be rich in protein (6). The seed coats contain pentosans, galactans and other carbohydrates, while the pods are rich in sucrose (66). Although too fibrous to be satisfactorily used as a stock feed, it is

claimed that mesquite bean pods are richer in sucrose than sugar beets. Apparently no thought has been given to the seeds as a source of edible oils.

Rubber

Attempts to use various domestic plants as possible standby sources of natural rubber to replace or supplement hevea latex have been numerous, and some are quite well known. Guayule (*Parthenium argentatum* A. Gray) and goldenrod (*Solidago* spp.) are perhaps the most publicized. Of interest also is the work of the U. S. Rubber Co. in cultivating the vine *Cryptostegia grandiflora* R. Br., indigenous to Madagascar, on a plantation near Yuma, Arizona. From the cactus *Opuntia vulgaris* Miller a latex was obtained which gave an amber-colored gum resembling plantation smoked sheet in color and guayule rubber in properties. The material can replace as much as 20% of smoked sheet rubber in compounding (42). Clark (18) has recently summarized the position of the domestic natural rubbers.

Food

The use of various cactus fruits as food and in food products is interesting, even if of minor commercial importance. Most widely known is the conversion of the barrel cactus fruit (*Ferocactus Wislizeni*) into cactus candy. The fruit of the Sahuaro (*Cereus* (*Carnegiea*) *gigantea* Eng.) was used by the Indians to a considerable extent. From the pulp a palatable syrup was made which was not unlike maple syrup or molasses. The syrup was fermented to make wine and vinegar. The dried pulp resembled dried figs to some extent, and the seeds served as a source of protein (34). Excellent tasty preserves and pickles can be prepared from the fruit of various cacti, after first removing the skin and spines. The leaves of the prickly pear are quite a delicacy—epicures stating that the cooked plant tastes like okra—"the best okra plus a strange, exotic 'something' ". The mucilage of the plant has a laxative action which is recognized by the medical profession (8).

Nordihydroguaiaretic acid, a very effective antioxidant for butter, fats and other food products, is being extracted from the greasewood bush (*Sarcobatus vermiculatus*) on a large scale by the Nordigard Corp., a subsidiary of the William J. Stange Co. The operation is being conducted with the collaboration of the New Mexico Agricultural Experiment Station at Las Cruces. The antioxidant is obtained by extracting the leaves and twigs with an aqueous solution of 5% sodium hydroxide and 2–3% sodium hydrosulfite. The extract is promptly acidified (30). The crude precipitate contains 10%–15% of the acid. The extracted precipitate is taken up in a low-aliphatic ether, and ethylene dichloride is added. The ether and part of the halide are distilled or evaporated until the solution is reduced to a thin syrup. The residual syrup is cooled, and the acid allowed to crystallize. The acid is then filtered and washed with ethylene dichloride (32).

Economic Factors

Many of the raw materials that the desert plants under consideration are

FIG. 14 (*Upper*). The vegetation on part of the desert plain in western Texas, consisting of guayule, *Parthenium argentatum*, an already exploited source of rubber; *Agave Lecheguilla*, the source of tula istle fiber; *Yucca* sp., other sources of fiber; mariola, and creosote bush, *Larrea tridendata*, a possible source of resins. (*Courtesy of the Texas Forest Service*).

FIG. 15 (*Middle*). *Agave* sp.; mesquite, *Prosopis* sp.; sagebrush, *Artemisia* sp.; and greasewood, *Sarcobatus vermiculatus*. Typical of the plains in western Texas. (*Courtesy of the Texas Forest Service*).

FIG. 16 (*Lower*). Creosote bush, *Larrea tridentata*, in Texas. Hen egg Mountain in the distance. (*Courtesy of the Texas Forest Service*).

known to contain, may be obtained from other sources, and frequently at a lower cost. World War II, however, has emphasized the need for further sources of raw materials which could be used in case of a national emergency. For this reason the potential value of the plants of the Southwest should be thoroughly understood so that immediate advantage of the knowledge could be taken, if necessary.

There are a number of economic factors peculiar to the American Southwest which, although not so great as a generation ago, nevertheless serve as a damper on efforts which might be made to utilize some of the products of the desert. These problems differ somewhat, depending on whether or not the desert plants are to be cultivated or utilized in the wild state.

The problem of cultivation of desert plants is one which has been side-stepped in considering the various uses to which the vegetation can be put. There seems to be a difference of opinion as to the feasibility of cultivation. In general, however, the following points may be made:

(*a*) Irrigation would be necessary, unless time were allowed for the plants to grow naturally under the semi-arid conditions of the region.

(*b*) Genetic studies might possibly be necessary. It has been contended that the content of the desired materials, such as alkaloids, might be considerably reduced if attempts are made to hasten growth by heavy irrigation.

(*c*) Individual consideration of each species would have to be given. For example, cultivation of mesquite for gum could probably be handled somewhat like a rubber plantation. Cultivation of some plants, such as Sahuaro for cellulose, undoubtedly would be out of the question, because of their slow growth. On the other hand, a cactus such as the prickly pear might be suitable for this purpose, since in some regions it grows rapidly enough to be classed as a nuisance, and steps have been taken to control it as a weed (22, 27).

(*d*) Frequency of harvest also depends on considerations peculiar to the individual case. For cellulose or fiber, a long and probably continuous harvest would be necessary. On the other hand, if alkaloids or some other product having considerable value were obtained, it might be possible to harvest biennially, or even at longer intervals; if it were necessary that the plants be cut down or uprooted.

(*e*) Transportation is one of the greatest economic problems. Since the region is undeveloped commercially, markets are some distance away, and the haul by railroad is difficult because of the terrain.

(*f*) Labor does not appear to be much of a problem. Before the war peon farm labor was available for $1.50 per day. Under present circumstances, however, this figure has almost certainly increased.

(*g*) Electricity and gas in the Southwest have been readily available, although electricity is now somewhat short because of the abnormally low rainfall combined with increased power demands over the whole area. The Colorado River projects have somewhat alleviated the situation, but at the present time the States involved are in disagreement as to the distribution of both power and water. Water is perhaps the basic problem—the general area of the Southwest has been undergoing a siege of drought for about 16 months. The rainfall in the region of Tucson, Arizona, for example, was about two inches for the year 1947, whereas the mean average over a 40-year period is about ten inches. There was no rain at all in July and August, 1947, while the long-range average for these two months is 4.3 inches. Several irrigation reservoirs have gone dry. The situation is very unusual, but does serve to emphasize the importance of water to the area.

Insofar as power for heat is concerned, an interesting observation may be made here. Gaylor (31) reports that the Russians are using a helioboiler in a fruit cannery near the Indian border. A 1500° F. heat is given, and boiler pressure of 150 psi. is obtained. The sunshine averages 280 days per year there. In the American Southwest the sunshine varies from 300 to 340 days per year. Several private homes have solar hot-water heaters, and the writer can vouch for their effectiveness. It is entirely possible that solar heat could be utilized in projects in the area.

The use of wild plants is, as a whole, undesirable for large-scale works, unless something like the greasewood bush, which is quite plentiful, is used. Even our pine forests require reforestation, and this same consideration applies to desert plants.

Two additional factors are concerned in the case of wild plants. There has been a natural opposition from stockmen to large-scale harvesting of the vegetation on their ranches. Cattle ranches cover a large portion of the territory under discussion, and some sort of working agreement would be necessary before a company harvesting wild plants could begin operations on a large scale. With a narrow margin of profit at best, this might be a limiting factor if too great a financial consideration were necessary.

The flower of the Sahuaro cactus is the State flower of Arizona. Hence these cacti are protected by State law, and the penalty for destroying one without permission is severe. The legal and aesthetic aspects of the destruction of any wild flora, even when replacement by young plants is anticipated, should be carefully investigated.

Summary and Conclusions

It would appear that although chemical utilization of desert plants is not immediately feasible, except perhaps in a few cases, there is considerable promise for future development. The most promising field seems to be that of alkaloids, products from which might be useful in the fields of antimalarials and other pharmaceutical applications. Cultivation of *Yucca* for its fibers, to be used in the manufacture of kraft paper, cardboard and other products, also offers outstanding possibilities for development.

The use of desert plants for production of alcohol, oils, resins, dyes and certain other products, and for utilization on a large scale for stock feed does not seem economically profitable at the present time. However, their potential utilization under changing economic conditions or in time of a national emergency should not be overlooked.

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Utilization Abstract

Jojoba. Seeds of the jojoba bush (*Simmondsia californica*), described in ECONOMIC BOTANY **1**: 401, have been collected by Dr. C. L. Lundell, Director of the Texas State Research Foundation, near Dallas, and distributed through county agricultural agents in 31 south Texas counties to farmers for test planting. This evergreen shrub, closely related to boxwood, is known also as "goat nut" and "pignut", and is native to the semi-arid regions of the American Southwest, extending into Mexico. The "seeds contain 50 per cent liquid wax and can be processed by any cottonseed oil mill. Aside from the wax which can be used in the manufacture of waxes and polishes, the bean has important medicinal agents, is high in protein, and its oil can be used in various food products. It contains a lubricant which has the characteristics of sperm oil, and finally the cake or meal after the wax is extracted can be used for plastics or as an excellent stock feed. Laboratory tests also show the oil to have properties which should make it valuable to the paint and varnish industries". (*Texas Chemurgic News,* as reported in *Chemurgic Digest 7(11): 13. 1948*).

Production, in Venezuela, of Indigenous Varieties of Tobacco

These varieties, still cultivated in a primitive manner, may have value for hybridizing with Burley and Virginia tobaccos. In Venezuela the leaves are manufactured into cigars or are extracted to produce the masticatories known as "chimo" and "tobacco rope".

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Duke University

During the past year the writer has had opportunity to observe practices used in Venezuela in the production of indigenous, or criollo, varieties of tobacco. From these observations it becomes quite apparent that the commercial methods of cultivating, harvesting, curing and processing the crop there, necessarily very primitive in the beginning, have remained quite unchanged during more than 450 years that have since elapsed. Nevertheless tobaccos of excellent quality and of great demand for cigar manufacture in certain European markets have been produced there year after year for a long period. For the reason that certain of these observations on the handling of native tobaccos are deemed to be of general interest they are recounted at this time.

Historical

Published information regarding the tobacco industry in Venezuela is relatively meagre. The account by Gornes MacPherson (1933) is by far the most comprehensive that has come to hand. Apparently the annual commercial production approximated 36,000 kilos as early as 1607. The crop increased some two hundred years later in the States of Barinas and Portuguesa alone to the extent that the accumulated profits said to have come into the possession of Simon Bolivar, the great liberator, largely provided him with means for prosecuting the war of independence of northern South America. By 1944–1945 the total crop of native tobaccos had increased to over six million kilos. Since that time production of these kinds has sharply declined in favor of rubio (golden or bright colored) tobaccos of the Virginia and Burley types. These milder flavored, lighter-colored kinds, used in cigarette manufacture, even though their cultivation has increased rapidly, are not being grown in sufficient amounts to meet consumer demands in Venezuela.

Native Common Names and Varieties

The difficulties attendant on determining the origin of vernacular names is always intriguing to a biologist. Many names were given by the Indians of tropical America, each tribe applying a different name, to the plant *Nicotiana tabacum* L., now known as "tobacco" throughout the world. This fact is mentioned by Gornes MacPherson. He states that the naturalist von Humboldt in 1789 recorded the names used by the peoples whom he encountered while exploring the coastal area of Venezuela from Cumaná westward to Caracas and thence southward across the Cordillera Costanera and the Llanos to the present Territory of Amazonas. Among these names are "azanem", "baniba", "baria", "caribe", "caruzana", "mandauaca", "mapoyo", "maquitare", "mangatu", "piapaco", "piaroa", "punsabe", "sal-libra", "uarao", "urareca", "uajibo" "yabarana", "yabarito" and "yaruro". Similarly a multiplicity of common names is employed at present for many other kinds of plants, especially trees, occurring throughout Venezuela and other parts of Latin America.

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[1] During the past year the author was employed in Venezuela by the Ministerio de Agricultura y Criá, collaborating with the Compañia Anónima Cigarrera Bigott, Sucs., and the Compañia Anónima Venezolana de Tabaco. To the many persons in each organization the author is deeply grateful for their help, especially to Dr. Clifford H. Meredith, Jefe del Departamento de Fitopatologiá.

At the outset one wishes that more records were available regarding the origin of the varieties that are indigenous to Venezuela and to adjacent countries. Apparently the early Spanish colonists found that the Indians living along the lower reaches of the Orinoco were growing a kind of tobacco that came to be known as "Orinoco". Undoubtedly this is the fundamental variety from which many of the strains of flue-cured tobacco, now grown in southeastern United States, were derived. These early colonists initiated the commercial culture of Orinoco tobacco in the area in which it is indigenous, and it seems probable that they employed, in other parts of Venezuela, other kinds which they found were being grown by the Indians, and which, perhaps, had been grown locally for centuries before the discovery of America.

It is of more than passing interest to note that relatively few varieties of indigenous tobacco now occur in Venezuela. Undoubtedly this is traceable to the fact that there have been no technologists in that country interested in improving the crop by selection and by hybridization. Each Venezuelan variety is well established and has long been known in each particular region. For example, there occurs in the State of Sucre in the region bordering the Golfo de Cariaco and extending eastward to Carúpano and El Pilár, an extensively-grown variety known as "Golfero". In the States of Barinas and Portuguesa, the variety Barinas, which is well known throughout the world, is widely grown, and in the States of Falcón and Lara, with the town of Cabudare as a marketing center, the variety Cabudare.

In addition there are Salóm, grown in the State of Carabobo in the environs of the town of Solóm; Cocorote, in the State of Yaracuy, near Cocorote; Guácharo, in the State of Monagras, in the vicinity of Caripe; Guanaguana, Cumanacoa, San António de Maturín, and Tranco Corto, in the region around Guanape in the State of Auzoátegui. Such other varieties as Chimó, Commún and Mundo Nuevo are also planted, each one usually in a different region.

Seed Beds or "Almacigos"

As with seedbeds everywhere, the essential features for their proper preparation concern selection of a suitable site and preparation of the soil. In general, well drained sites on uncultivated land are chosen, such as may be found near the base of a hill or mountain, or on a slope near a stream. The natural vegetation of such places usually consists of shrubs and trees. By means of "el machete" (large knife) and "la escardilla" (hoe) the seedbed site is cleared and the soil loosened to a depth of three or four inches. In so doing the leaf mold and decaying leaves are thoroughly incorporated in the loosened soil. The seed are then sown, usually during August which occurs near the middle of the rainy season. Very little seedbed care, such as weeding and watering, is required, and the seedlings will be of sufficient size for transplanting early in October. Losses in the seedbeds from damping-off diseases ("sancocho") are inconsequential.

Such seedbed practices, because of their simplicity, are markedly different from those used in growing Virginia and Burley types in Venezuela. For such types, by use of plows and shovels, the surface of the beds is elevated ten to 20 centimeters or more above the surrounding terrain to secure adequate drainage and to prevent flooding. Then a cover is provided to protect against

FIG. 1 (*Upper*). A caney of the kind commonly used for air-curing indigenous kinds of tobacco in Venezuela.

FIG. 2 (*Lower*). Cultivating tobacco in Venezuela with a special implement pulled by an ox (buey).

torrential rains and intense sunlight. These covers are constructed of pole frames with a roof of a grass, known as "gamelote" (*Panicum maximum* Jacq.), or of banana or palm leaves. The covers must be removed and replaced daily to permit suitable illumination, and the beds must be watered frequently. Under these conditions damping-off, induced by species of *Pythium, Rhizoctonia* and *Sclerotinia,* may cause such severe losses as to be a limiting factor in the production of seedlings.

The causes for differences in incidence of damping-off in seedbeds for these different types of tobacco remain unknown. But since each grower of native tobacco raises from 1,000 to 50,000 plants only, his seedbeds are small. On the other hand, those who grow Virginia and Burley types may plant areas varying in extent from ten to 100 hectares, and hence each farmer requires large seedbeds. The growing of a large population of seedlings in a restricted area, as must be done with Virginia and Burley types, may favor significantly the incidence of damping-off. It seems more likely, however, that the difference in disease incidence is attributable primarily to difference in degree of disturbance of microbial balance in the soils during preparation of the seedbeds. Observations indicate that antibiosis in the control of soil-borne pathogenic fungi is a significant factor, at least to the extent that it is worthy of consideration in proper seedbed preparation and management.

Field Practices

Mountain sides, even those having a declivity of as much as 75 per cent, are sometimes cleared and planted to tobacco, but the more nearly level valley lands, which are of alluvial origin, are generally used. Such soils have long been known to be the most suitable for tobacco production (3). In fact in one valley a farmer when asked how long tobacco had been grown there responded "Yo lo creo que el tabaco ha sido crecido aquí después el principio del mundo" (I believe that tobacco has been grown here ever since the beginning of the world).

For the most part, each farm ("hacienda") comprises from one to fifty thousand hectares on which tobacco is cultivated in small parcels. The landowner ("latisfundista") and the tenant or small grower ("conuquero") arrange terms for the cultivation of each small tract. The basis of terms may be a share of the crop or a fixed price per kilo of cured tobacco. Not uncommonly also the terms include credit for supplies of food and clothing for the grower and his family. Sometimes such credit is advanced by a merchant, especially if he is also a tobacco dealer.

In many instances the escardilla and machete are the only implements available for use in preparing and cultivating the fields, but sometimes, by arrangement with the landowner, ox-drawn or tractor-drawn plows and disc harrows are used for this purpose. The field is not laid off in ridged rows in preparation for transplanting, as is done with Virginia varieties in the United States, but is kept quite plane. Commercial fertilizers are not used at all. The seedlings may be transplanted in rows a meter or more apart or may be interplanted in the middle of rows of nearly mature corn. In the latter event, the weeds and grass must first be removed with a hoe, and the seedlings are transplanted near the center of these small cleared patches. Essentially all subsequent cultivation is done with a hoe, the weeds are kept cut off, and by the time the dry season has begun, a layer of loose soil has been formed which provides a mulch and helps to conserve soil moisture.

Harvesting and Processing

All native tobaccos are harvested by picking the leaves a few at a time as they mature, beginning with the lowermost and progressing toward the top of the plant. The length of the harvesting period depends upon two things, the topping practices and the rains. Plants are generally topped as soon as the inflorescences are of sufficient size to be grasped by the finger tips and broken off. Suckers ("chupones") then develop, and each of them, too, may be topped early. If the tops are removed from all suckers as soon as they appear, the plants will continue to vegetate, and, provided rainfall is adequate, each plant may produce from 50 to more than 100 sucker leaves, all of which are harvested. Under such conditions there may be four pickings of main leaves, and five or six pickings of sucker leaves during a period of six to eight months. In rare instances the main stems are cut off immediately after harvest, new shoots are then permitted to develop, and when their leaves are harvested, the stems are again cut off. By so doing repeatedly, and by avoiding flowering and fruiting, the plants continue to vegetate for a year or even for several years. The leaves borne on the primary stems constitute the main crop ("cosecha principál"), and all other leaves are "los ratoñes".

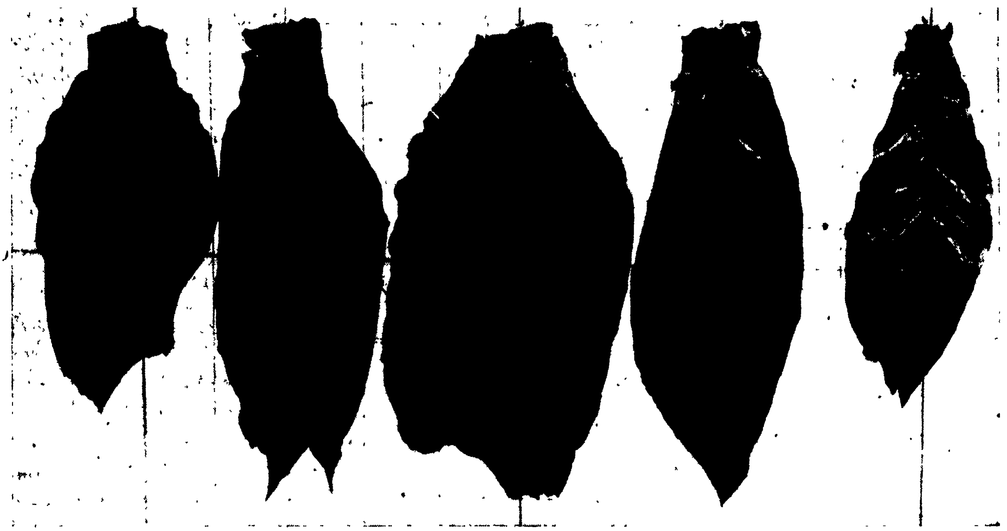

Fig. 3. Leaves of five native Venezuelan varieties of tobacco. Leaf size is shown by the 10 cm². square grid in the background. From left to right the varieties are Salóm, Cocorote, Chimó, Tranco Corto, Guácharo.

The tobaccos are mostly air-cured, but some may be sun-cured. For air-curing, shelters ("caneyes") are used, which are constructed of poles lashed together with bark fibers ("majágua"), and the roof is thatched, usually with gamelote. The racks for sun-curing are built of poles and are placed at convenient points in the field. When the leaves are almost cured they are transferred to a shelter to complete the curing and to store them.

In preparation for curing, the leaves are fastened to ropes ("cuerdas") made of bark fibers. This is done by enmeshing bundles of leaves while the fibers are being braided into ropes.

The strings of leaves thus formed are then hung, hammock-like, in the caney, the length of the string being conditioned by the caney's length.

As soon as the leaves are cured, and at times when they have absorbed sufficient moisture to be handled without breakage, they are graded in preparation for being taken to market. Leaf size is a most important feature in grading. Size is determined by grasping the base of the leaf by the fingers, and the leaf tip is then extended up the arm. Those leaves having a length to extend from the finger-tips to the elbow are of one grade, those not so long are of another grade, and all longer ones are in third grade.

There is no price discrimination between los ratoñes and la cosecha principál. Sometimes rains adversely affect the quality of the latter, however, and it is not uncommon that the ratoñes are the more desirable because they are the heavier-bodied and the more aromatic. After being graded and tied into hands, the tobaccos, whether in possession of the grower or dealer, are arranged in piles, whereupon they undergo fermentation. During fermentation the light-brown and yellow-brown colors of carefully cured leaves change to become considerably darker, and the characteristic cigar aroma is developed.

Uses of Tobacco Other Than in the Manufacture of Cigars

A large proportion of this kind of tobacco is ultimately used, either abroad or locally, in the manufacture of cigars, but a part is always utilized in making two other products, "chimó" and "tobacco rope" ("cuerda del macho o burro", "tabaco al masticar").

Chimó is a thick, tarry, dark paste, prepared by extracting the ripened leaves and the suckers in caldrons of boiling water. The extractive is then evaporated until the residue has a very thick consistency, whereupon it is placed in barrels and marketed. The buyer then puts it into jars or other suitable containers, or small lumps of it are wrapped in waxed papers for sale to consumers. Those who use chimó hold it in their mouth in quite the same way as is done by those who dip snuff.

Tobacco rope is a form of chewing tobacco. It is prepared by extracting the leaves, as is done in making chimó, but the extractive is afterward absorbed by the boiled leaves and applied to them. This is done by dipping the leaves in the extractive while they are being twisted tightly into ropes. The ropes are next air-dried. Then at the time of sale to the consumer or user these ropes are cut into the desired lengths.

Characteristics of the Leaves of Certain Indigenous Varieties

To learn more about the features of certain of the native tobaccos than is possible from field observations in Venezuela, seeds were gathered and were used to grow plants at the Tobacco Experiment Station, Oxford, N. C., during the summer of 1948. The examinations made of these varieties included determination of the population of glandular hairs and leaf size by methods described in a previous study (1). Certain of these data are summarized in Table 1.

These five varieties evidently belong in two quite distinct groups. Chimó is definitely in a group with cigar-filler tobaccos, not too unlike kinds being grown in Pennsylvania and Wisconsin. The other four are all closely related and have the appearance of flue-cured varieties, especially such kinds as Lizard's Tail, Little Orinoco, Warne and Adcock which were popular among growers of flue-cured tobacco a generation ago. The leaves of Guácharo are the smallest and narrowest. All four varieties have a similar per unit-area population of glandular hairs and all are very aromatic. In fact their per unit-area hair population is essentially the same as that of the most aromatic of the 80 or more varieties of Turkish tobacco that the writer has examined (1, 4).

It seems probable that environment has induced an increase in hairiness of Venezuelan varieties during the several hundred years of commercial cultivation. The natural infertility of the soils and the non-use of commercial fertilizers have caused slow plant growth. Extended periods of paucity of soil moisture and intense illumination have also exerted an influence unfavorable for rapid growth. No doubt, too, such plants as were most tolerant of these conditions year after year have served as sources of seed for each succeeding crop, and thus the net result has been increased resistance to drought and increased hairiness with a correlated increased volume of aroma.

TABLE 1

SOME LEAF CHARACTERS OF VENEZUELAN VARIETIES OF TOBACCO

Varietal name	*Number of leaves per plant*	*Average number of hairs per cm²*	*Average leaf area, cm²*	*Average hair population per leaf in thousands*
Chimó	24–25	1146	1341.3	1537.9
Guácharo	23–27	1740	490.6	852.3
Tranco Corto	19–21	1606	654.2	1262.4
Salóm	26–35	1525	731.4	1126.3
Goncorote	24–28	1758	816.3	1271.4

Leaves from each of the five varieties, when grown at Oxford, N. C., were harvested, and some from each picking were then air-cured; others were flue-cured. When air-cured their color and texture were like those of Burley tobacco. Indeed it was the opinion of expert tobacconists that they constituted very acceptable Burley tobacco. When flue-cured, however, the tobacco was yellow-brown, papery and of such poor quality as not to be particularly desirable as flue-cured tobacco. In any event these varieties can not be expected to compete successfully where excellent varieties of Virginia and Burley are already established.

General Considerations

It should be borne in mind that native Venezuelan varieties of tobacco grow slowly, are late maturing, and their leaves have a dense population of glandular hairs. After several years of study by the writer and his associates it was determined that such features in Turkish varieties of tobacco are correlated with desirable "quality". It should be added that the determination of what constitutes desirable features of Turkish tobacco and of how to grow a crop having desirable quality required several years of painstaking effort, whereas, in contrast, tobaccos with such characteristics have been developed in Venezuela without any purposeful efforts, without knowledge of developments in tobacco technology in other parts of the world, and without the intervention of scientists. Moreover, each Venezuelan variety has a high degree of uniformity. In fact, they are so uniform that their production would reflect credit to anyone having a background of knowledge of the principles of hybridization and selection.

It remains to be demonstrated that any of the Venezuelan kinds will prove valuable as stocks for hybridization with Virginia and Burley varieties, to be grown in the United States, but such use is indicated as a means of securing resistance to drought and to diseases. In the writer's opinion, if more care were given the leaves during curing and subsequent storage in Venezuela, the resultant tobacco should be acceptable in the manufacture of bright-colored cigarettes.

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Utilization Abstract

Yerba maté. "Yerba maté or yerba de maté, also known as Paraguay-tea, is a plant whose leaves are prized in South America for beverage making. This beverage is similar in taste and chemical composition to tea and likewise has a stimulating and refreshing effect on the drinker. The tree is a kinsman of the holly and grows from Bolivia and Mato Grosso, Brazil, to northern Uruguay and the Argentine Province of Corrientes. The beverage is most commonly made from the leaves of the species *Ilex paraguariensis*.

"The yerba maté tree prefers ravines or depressions in the foothills and mountains at elevations of from 1,500 to 2,500 feet, a damp humid climate, and deep, alluvial soil containing large amounts of humus. The Paraná pine is usually a close neighbor in the forest, sometimes providing shade for the yerba maté tree. Brazil is the principal producer of maté, followed by Argentina and Paraguay. Most of Brazil's maté production comes from wild forests, where the trees sometimes grow to a height of 80 or 100 feet. When grown on plantations, the trees are usually pruned and range from 12 to 30 feet in height.

"Harvesting begins when the tree is 4 or 5 years old and is carried on from May to October when the leaves are dry. Leaves are gathered from the same trees preferably not oftener than every second or third year. Workers cut the small branches, toast the leaves evenly by holding the branches over a bonfire, and then place them in a barbacuá or ovenlike structure for drying. The mass of branches and leaves is stirred frequently during the 4- or 5-hour drying process, after which it is taken to the threshing floor. After the leaves are separated from branches and other waste material, they are finely ground, sifted, and graded.

"Maté has not yet gained popularity outside South America. That imported into the United States in 1947, for example, totaled only 21,000 pounds, compared with 67,448,000 pounds of tea and 2,500,000,000 of coffee. It is a "must" item, however, in the daily diet of many of our neighbors in Argentina, Brazil, Paraguay, and, to a less extent, in Uruguay and Chile. Prewar production of maté amounted to 368,000,000 pounds, approximately one-fourth as much as the world tea output". (*Foreign Agriculture 12(5) : 111. 1948*).

The "Palo de Tomate" or Tree Tomato

Widely known throughout the tropics of the world but not abundantly cultivated outside its native Andean home, this fruit offers a desirable addition to the food resources of warmer climates.

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Federal Experiment Station, Mayaguez, Puerto Rico

Cyphomandra betacea (Cav.) Sendt., "Palo de tomate", "Tomate de arbol" or tree tomato, is generally considered a native of Peru. It is abundantly cultivated and highly esteemed in many parts of the inter-Andean region where it is one of the most popular fruits. Although not commonly known, it is grown in many parts of the world. In the warmer sections, such as Malaya and the Philippines, it is successfully cultivated only at higher elevations, for it grows poorly and seldom fruits in the hot tropical lowlands. In Ecuador it is grown between 5,000 and 10,000 feet. In cooler climates cultivation is possible down to sea level.

In Puerto Rico the plants grow best in the mountain section, but satisfactory growth has been observed near Rio Piedras at an elevation of less than 100 feet. In the Toro Negro Unit of the Caribbean National Forest and in a number of other hill sections, from 1,000 to 3,000 feet elevation, the plants produce fruit without benefit of cultivation.

The tree tomato as it grows in Puerto Rico is a woody shrub sometimes approaching the size of a small tree, 12 to 18 feet tall and two to four inches in diameter near the soil surface. Exceptional plants may reach a height of 25 feet. At higher elevations the plants are smaller. The cordate, ovate leaves are three to 12 inches long. The lavender pink flowers, half to three quarter inch in diameter, are borne in small, axillary cymes near the ends of branches and appear at the beginning of the rainy season, usually in April or May. The two-carpeled fruits are red to orange, the size and general shape of a hen's egg but more pointed. They ripen in October and remain on the trees until January.

The culture of tree tomatoes has probably been most extensive in the Far East where purple varieties are also grown. It is commonly grown in the hill-country gardens of Ceylon where it fruits almost throughout the year, but chiefly from March to May. The tree is a quick grower, commencing to bear when one and a half to two years old and becoming unproductive after five to six years. It comes into bearing earlier from cuttings, but seeds are also satisfactory.

The succulent, subacid fruit is generally considered to taste like a tomato. However, some believe it is also similar to gooseberry and passion fruit. When cooked the flavor suggests apricots. It has a rather distinct and pleasant aftertaste. In fact a flavor differential exists. The meaty mesocarp, or flesh just inside the skin, has a bland cheesy flavor, while a watery, slightly acid, but sweet pulp surrounds the seeds. The fruit may be broken open and eaten raw. Some people do not consider them so satisfying as better known fruits, but others regard them as refreshing and agreeable. A more common method is to stew the fruits to form a conserve or "dulce".

The skin is tougher than in the cultivated tomato and has a disagreeable flavor. It should be removed before cooking. This is easily accomplished after immersing the fruit in boiling water for a minute or two. While garden tomato seeds can usually be included in the final product, the seed of the tree tomato should be removed from the pulp because they are harder than those of the tomato and bitter in taste. The pulp can be passed through a coarse strainer before cooking with sugar. The resulting preserve can be improved by addition of cinnamon and salt.

The tree tomato can also be used in curries, mixed vegetable dishes, soups, and for most of the uses of the garden tomato.

The tree tomatoes are popular in their original home and many other sections of the world. The hill country residents of Puerto Rico usually cook them without removal of the skin and seeds. Since this factor is of sufficient importance to make the difference between a desirable and an undesirable fruit, it is easy to understand why they are not more widely used.

The tree tomato should not be con-

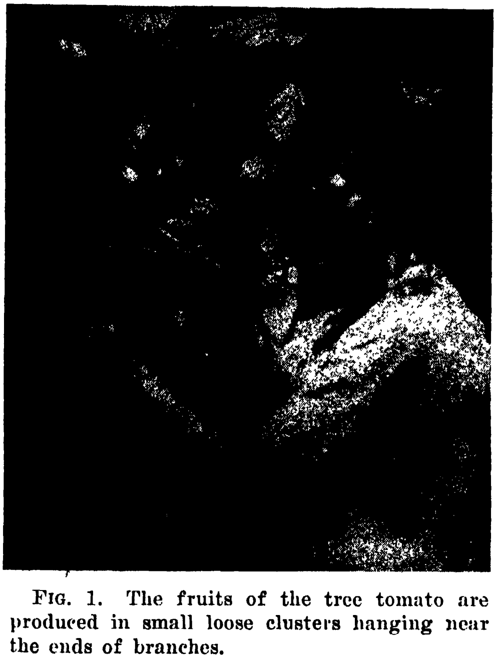

FIG. 1. The fruits of the tree tomato are produced in small loose clusters hanging near the ends of branches.

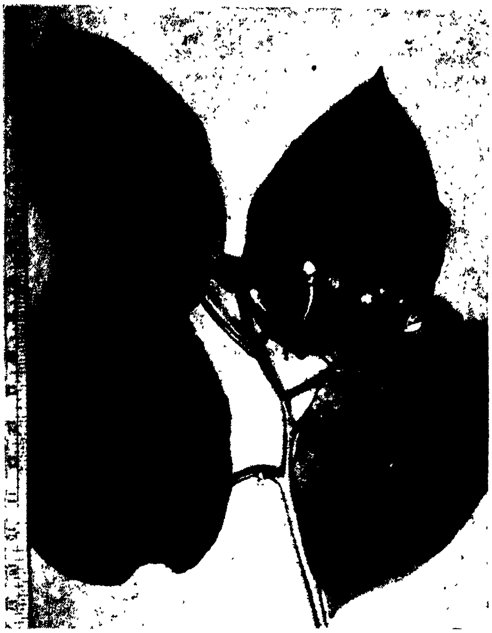

FIG. 2. The lavender or lavender pink flowers are ½ to ¾ inch in diameter and resemble those of a tomato.

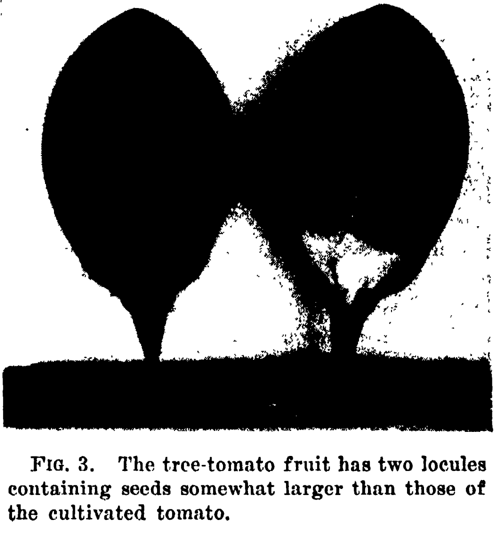

FIG. 3. The tree-tomato fruit has two locules containing seeds somewhat larger than those of the cultivated tomato.

fused with the naranjilla, *Solanum quitoense* Lam. Both belong to the same family and are native to the same general area. The densely pubescent fruit of the naranjilla is nearly spherical, and its purplish leaves are long and usually spiny. Its chief use is as a juice or "jugo".

The tree tomato has received little attention from plant breeders. It is quite possible that it is as good as or better than the garden tomato was before extensive breeding work on the latter was begun. It is also possible that by selection and hybridization this fruit might be similarly improved. Francis O. Holmes of the Rockefeller Institute for Medical Research at Princeton, New Jersey, has shown that this is one of the only two hosts of all he has tested which was resistant to the virus of tobacco mosaic.

This crop appears to have considerable value for those living in tropical highlands because of its resistance to insects and diseases and its ability to grow with little or no culture, even in high rainfall areas. Culture would undoubtedly result in greater yields. An additional advantage is that the fruits mature at a season when few fresh vegetable products are available. A few plants in the home garden could add considerable to the family diet. Also, the tomato which it resembles does not thrive at higher altitudes where the tree tomato is best adapted. A limited export trade might be developed with this specialty fruit.

Utilization Abstract

Chlorophyll. Commercial production of chlorophyll is expected to begin sometime this year in a new extracting plant to be located in Rockford, Ill. In this plant alfalfa will be used as the principal raw material during the northern growing season, and spinach, shipped from the South, during the winter. The chlorophyll produced will be used for medical purposes, since it is believed by the sponsors of this project that chlorophyll, extracted in its natural form, can be administered to prevent or correct either an overactive or underactive metabolism and will have beneficial effects in the treatment of arteriosclerosis, hypertension, heart disease and fatigues. (*Chemurgic Digest 8(3): 16. 1949*).

This chlorophyll-extraction work, which was reported in ECONOMIC BOTANY **2**: 362. 1948, has been developed by Dr. Boris Berkman and his sister, Dr. Sophia Berkman, both of Chicago. The former directed the Government-sponsored extraction of milkweed floss during World War II, and an article by him on that work will appear in the next issue of ECONOMIC BOTANY.

Safflower*

A potential oilseed crop in the western States

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Introduction

SAFFLOWER is an oilseed crop which for many years has been grown on a relatively small scale in parts of North Africa and the Middle East. Its production in Egypt dates back some 3,500 years, as indicated by seeds found in the graves of Pharaohs (8). In very early times it was cultivated primarily as a source of red dye (carthamin) obtained from the flowers and secondarily as a source of oil obtained from the seed. At the present time it is grown in foreign countries only as a source of oil or grain which is commonly fed to poultry and livestock.

During the period of 1925 to 1935 a number of Agricultural Experiment Stations and farmers in the Midwest and western States made trial plantings of safflower in cooperation with the U. S. Department of Agriculture. The results of these tests were summarized by Rabak in 1935 (6). He concluded that safflower offered some possibilities as a dry land and irrigated oilseed crop in the northern Great Plains and western States. The varieties tested were of Russian origin and contained only 22 to 26 per cent oil. Interest in safflower from 1935 until the beginning of World War II generally declined. Many States discontinued all tests with this crop. However, during this period a few varieties with 28 to 31 per cent oil were introduced from India and Turkestan by the U. S. Department of Agriculture and by Mr. Alfred Rehbein, Sr., a Montana farmer.

In 1941 the Nebraska State Legislature established the Chemurgy Project at the University of Nebraska. One of the functions of the project was to determine the feasibility of producing new crops which could be used industrially in Nebraska. Safflower was one of those considered in this category. In 1942, the first year of agronomic tests, many varieties of safflower which were then available in this country were grown at eight locations in the State. From production tests in western Nebraska that year and the results of previous tests by several Agricultural Experiment Stations, the crop was thought to show sufficient promise to merit the establishment of an extensive breeding program in this State. As a result of this work a variety which averages 34 per cent oil is now available for increase. The purpose of this article is to stimulate interest in safflower as a source of oil and meal in areas where it is adapted; to present recent data on varietal and cultural tests; to discuss some of the accomplishments and possibilities in breeding for higher oil content; and to present the current status of commercial production in the United States.

Characteristics and Adaptation

Safflower, *Carthamus tinctorius* L., belongs to the Compositae, subfamily Cynareae, commonly known as the thistle family. It is a much branched, herbaceous annual. All branches are terminated by an individual head composed of 20 to 80 florets. Each floret may produce one seed. It attains a height of 16 to 48 inches, depending upon variety and moisture conditions. From the farmer's viewpoint safflower has both good and bad characteristics. Good features are that it does not shatter, is not subject to bird damage and does not lodge. Undesirable characteristics are spininess of present varieties, susceptibility to grasshoppers and slow growth in early spring which contributes toward poor weed competition. By breeding it is possible to largely eliminate these undesirable features.

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* Reprinted from Chemurgic Digest 7 (3): 11. 1948, except statistics and other details of experimentation.

Safflower is adapted to areas which have dry atmospheric conditions from time of flower bud formation until after maturity. Low relative humidity is essential for good seed-set and high oil content. The area of adaptation is thus limited to regions which have arid or semi-arid climates during the latter part of the growing season. In the United States safflower is adapted to the western part of the northern Great Plains and that part of the Pacific Northwest located between the Cascade and Rocky Mountains. In order to mature in this area, the growing season must be at least 120 days. It may also be adapted to parts of southwestern United States as a fall planted crop. The crop is apparently not adapted to the corn belt, or to eastern or southern United States.

For the past several years safflower seed of the more promising introductions and selections has been sent by the Chemurgy Project of the University of Nebraska to a number of Agricultural Experiment Stations in other States for regional uniform testing. Results from these tests are now showing where safflower is best adapted and whether this crop can compete with existing crops in areas where it is adapted.

Utilization of Oil and Meal

The oil content of existing safflower varieties varies from 19 to 34 per cent. Several lots of seed have been successfully processed by an expeller unit in the Nebraska Chemurgy Laboratory. Results of these tests have been published (10). Safflower produces a drying oil which is characterized by high linoleic acid content (approximately 75 per cent) and very low linolenic acid content (0 to trace). The iodine value of the oil ranges from 140 to 150 (1). Without the addition of driers, the rate of thickening of safflower oil is slower than that of linseed oil, particularly during the initial stages. In the presence of driers safflower oil dries as fast as linseed oil (5). In India the oil is utilized mostly for culinary purposes (7). The seed and oil produced in foreign countries is for the most part consumed locally and seldom enters world trade.

Carrick and Nielsen (1) studied the possibilities of safflower oil as a vehicle in protective coatings. They concluded that safflower oil would be satisfactory as a vehicle in outside paints, inside enamels, as a source of heat-treated oils of high linoleic acid content and in the preparation of alkyd resins. Pugsley and Winter (5) concluded that, "Safflower oil could replace linseed oil in most organic coating compositions, and in some instances improved coatings would be obtained". It therefore seems likely that safflower oil in the United States may find more profitable utilization in the paint, varnish and allied industries than as an edible oil.

The Department of Animal Husbandry of the University of Nebraska compared safflower meal containing a crude protein content of approximately 42 per cent with soybean meal for wintering calves and for fattening yearling steers. The Scottsbluff Substation compared the same oilseed meals for fattening lambs. Daily gains in all three feeding tests were slightly higher with the safflower meal (9). The crude protein content of safflower meal may vary from 20 to 55 per cent, depending upon variety, protein content of whole seed, and the percentage of hulls removed previous to processing. More experimental data are needed to determine the proper percentage of hulls to be removed for best processing and feeding results.

Varietal Experiments

Kupzow (4) has made an extensive study of the geographical variability of safflower. He found that there were distinct geographical types. Introductions made by the Nebraska Chemurgy Project from a number of countries of North Africa and the Middle East confirm Kupzow's findings. There apparently has not been a great deal of interchange of safflower varieties between countries of the Middle East and North Africa. Evolutionary changes in this crop have obviously been progressing at several secondary centers of origin. Complete spinelessness has been found only in introductions of the Afghanistan type. North Africa has been the best source of high oil content varieties. According to Kupzow's (4) detailed descriptions of safflower from different geographical areas, there are apparently many types in existence which have not yet been introduced into this country. Introductions and selections developed by the Nebraska Chemurgy Project breeding program have been compared for yield, oil content and other characteristics.

Safflower plots in rows ten inches apart (solid drilled) were planted at the rate of 30 pounds per acre, and plots in cultivated rows 40 inches apart were planted at the rate of 15 pounds per acre. There were no significant differences in yield between row spacings. Flowering commenced approximately two days earlier and maturity occurred seven to ten days earlier in solid drilled plots than in cultivated rows. Nebraska 852 yielded significantly higher than all other varieties. The interaction between varieties and row spacings was significant. A planting rate of 30 pounds per acre in solid drilling for Afghanistan types may be too heavy for maximum yields.

A comparison of test weight and oil content in the seven safflower varieties planted shows that high oil content is not related to high test weight. Test weight is a characteristic of geographical types and does not necessarily indicate oil content. Introductions from Africa grown in Nebraska vary in test weight from 38 to 45 pounds per bushel. Hindustan and Russian introductions are high in test weight, 42 to 49 pounds per bushel. The Russian varieties are exceptionally high in test weight and low in oil content. Afghanistan types are intermediate in test weight, 40 to 47 pounds per bushel.

Limited data indicate that there may be a positive correlation between test weight and oil content within the same variety. Irrigation seems to lower both test weight and oil content of all varieties. In the purchase of seed by industry the variety should be taken into account before placing any emphasis on test weight. Varieties can often be recognized by seed characteristics. For example, N-852 seed can easily be recognized from Indian safflower by the longer and narrower seed shape. The hull on N-852 also has more pronounced ridges than Indian.

Since the uses of safflower oil appear to be similar to those of linseed, it is important to determine the relative yielding ability of the two crops. Data on the comparative yields of these crops during a four-year period on fallowed and non-fallowed land in western Nebraska indicate that safflower yields on the average 20 to 25 per cent more pounds of seed per acre than flax. The margin of safflower over flax is the highest when soil moisture conditions are favorable. Under droughty conditions on non-fallowed land flax usually yields as much as or more than does safflower. Under irrigation safflower often yields 50 to 75 per cent more seed per acre than flax.

Since flax matures approximately one

month earlier than safflower, flax escapes the effects of droughts which occur during the later part of the growing season. More data are needed on the comparative yielding ability of these two crops grown under the variable climatic conditions of the western States.

Cultural Experiments

One phase of the safflower research program in Nebraska has been to determine the most satisfactory production practices. Experimental results from 1942 to 1944, inclusive, have been published (3). Some of the more pertinent data on production practices obtained during the past three years are presented in the original publication of this article in the Chemurgic Digest.

Breeding for Higher Oil Content

An important part of the safflower breeding program has been to develop varieties with high oil and low hull content. During the past few years some 500 to 700 oil and hull analyses were made each year on seed from individual plants selected from the better introductions. These analyses have shown that there is a strong negative relationship between oil and hull content. Seed which contains a high percentage of oil will contain a low percentage of hull. The oil content of seed introduced from North Africa and the Middle East has varied from 22 to 34 per cent. Seed from most introductions contained less than 30 per cent oil and more than 50 per cent hull.

Most introductions are not pure for oil content. For example, single plant reselections from the Special Russian variety vary in oil content from 17 to 38 per cent, and in hull content from 35 to 64 per cent. The Special Russian variety averages approximately 29 per cent oil.

A number of individual plants originally selected from varieties of three distinct types contain from 37 to 39 per cent oil. By reselecting in the progeny of these plants, it should be possible to purify lines that will average 36 to 37 per cent oil within several years. In order to increase oil and reduce hull content still further, crosses are now being made between high oil content plants of distinct types.

Present Status of Commercial Production

During the 1930's farmers in Montana grew a few thousand acres of safflower of the Russian varieties. As previously stated, these varieties contained only 22 to 26 per cent oil. The few quotations made by industry for safflower of that oil content were not high enough to encourage production.

During the past four years, 8 to 20 farmers located in western Nebraska have been growing several hundred acres of Indian safflower each year. In 1946 Cargill, Inc., became interested in promoting and processing safflower. As a result of this interest, in 1947 there were approximately 4,000 acres grown. This acreage was centered in southeastern Montana. Seed produced on this acreage which was not kept for 1948 planting was purchased by Cargill, Inc., for 75 per cent of the prevailing flaxseed price on a poundage basis. Approximately 1,200,000 pounds of seed were processed. A production of 15,000 acres of safflower was estimated for 1948. This acreage was widely scattered in Montana, Nebraska, Washington, Idaho, Oregon and North Dakota.

Indian safflower has been the only variety grown during the past four years. Seed from this variety averages 28 to 30 per cent in oil. Although it is very impure, most plants are spiny. Orange is the predominant flower color. At the present time it is the only variety available in quantity for commercial production.

Nebraska 852, an introduction from the Anglo-Egyptian Sudan, is now in the process of being increased for commercial planting. It is reasonably uniform for type but is not pure for flower color. The predominant flower color is yellow. This variety averages 34 per cent oil. It is distinctly different from Indian, is superior in yield and rapid growth early in the season. N-852 is more susceptible to grasshoppers than Indian. A total of 3,500 pounds of

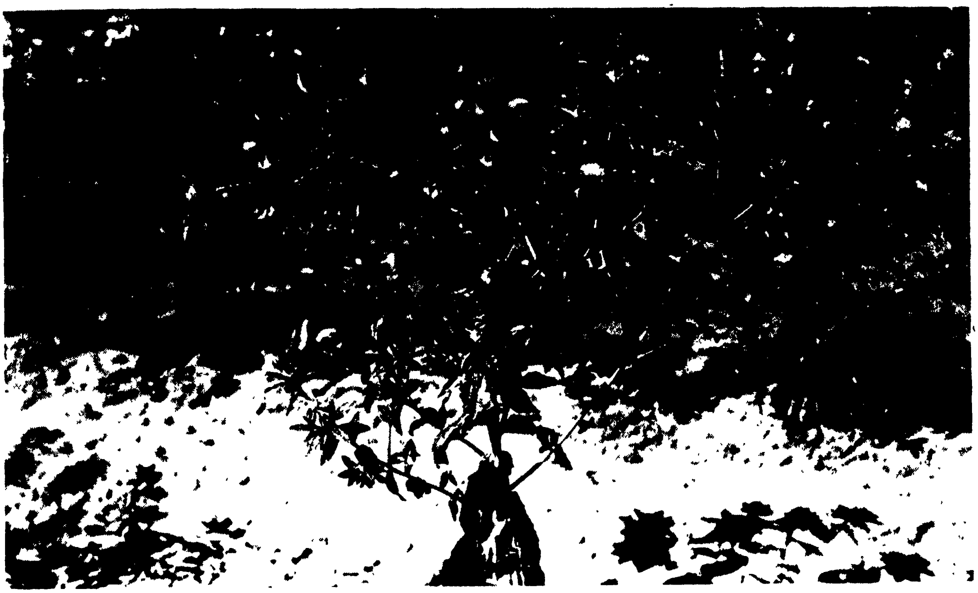

Fig. 1 (*Upper*). African Sudan type of safflower.

Fig. 2 (*Lower*). Field plots of safflower planted in solid drilling and in 40-inch rows at Alliance, Neb., 1947.

N-852 was released to Nebraska farmers and to a few Agricultural Experiment Stations in the western States for planting in 1948.

Nebraska 55, a selection made in 1943 from Pusa 14, is being increased in Oregon. This selection is similar in appearance and yield to Indian. Its chief advantage over Indian is that it has 1 to 1½ per cent more oil. It is uniform for type and is pure orange flowered. In 1947 a total of 5,500 pounds of Nebraska 55 seed was produced in northeast Oregon.

A number of other Nebraska selections have been increased to a few pounds. Some of these selections are spineless and contain 29 to 30 per cent oil. These will be tested for yield during the next several years and may be released later.

Recommendations for Seed Increase

During the past four years some difficulty has been encountered in maintaining pure safflower seed of good quality. Small grain and some weeds such as wild sunflowers are difficult and in some cases impossible to separate from safflower seed with the usual type of seed cleaner. In order to maintain pure seed supplies the following suggestions are made: (*a*) Safflower for seed increase should be planted on summer fallowed land. If this is not possible, it should follow some crop other than small grain or safflower. (*b*) Planting should be in cultivated rows 36 to 42 inches apart so that the field can be rogued if necessary. It is easier to rogue if not more than five to eight pounds of seed per acre are planted. The best time to rogue safflower is immediately after the last cultivation which normally occurs during the latter part of June or the forepart of July. The spines are not so objectionable then as they are later in the year. (*c*) Since safflower is cross-pollinated from 5 to 100 per cent by insects (2), seed increase fields should be isolated from other safflower varieties at least 40 rods and preferably considerably farther. (*d*) Harvesting should be done soon after maturity so that germination will not be reduced by fall rains.

Harvesting

Because of spines on the leaves of most varieties now available for commercial production, combine harvesting is essential. Since the crop does not shatter or lodge, harvesting can be delayed two to four weeks after maturity, if necessary, to fit other labor needs on the farm. Delayed harvesting is not advisable if seed is to be used for planting. In order to prevent cracking the seed, it is essential to reduce cylinder speed to approximately 500 r.p.m. Proper wind and sieve adjustments of combine will remove practically all leaves, stem parts and unfilled seeds. There is usually a low percentage of unfilled seed in all safflower grown.

Conclusions

In the past safflower has been an oilseed crop of only minor importance. It appears now that this crop can be sufficiently improved by breeding so that in the near future it may be of considerable economic importance in western United States. Experimental data on safflower oil indicate that it would be satisfactory in the paint, varnish and allied industries. Feeding experiments with the oilseed meal from decorticated (hulled) seed show that it is at least equal to soybean meal in feeding value.

Data presented on production practices show that safflower in western Nebraska should be planted between April 10 and May 5. Planting can be either in solid drilling, as in wheat, or in cultivated rows. In solid drilling, safflower competes with weeds better than does flax but not so well as do the small grains. There is wide variation in satisfactory planting rates.

Nebraska 852, an introduction from the Anglo-Egyptian Sudan, is the best variety now available for production. New varieties are, however, being developed at the University of Nebraska which will be superior in yield and oil content to Nebraska 852. These should be available for planting within a few years.

Since the oil content in safflower seed is so variable (19 to 38 per cent), the oil percentage of the variety considered for commercial production will have a direct bearing on the price which can be paid for the seed. Varieties which average less than 28 per cent oil should not be considered for this purpose. As soon as varieties which average 34 or more per cent oil are available, it seems probable that safflower will find a permanent place in the agriculture of a number of western States. The production of safflower would add another cash crop to areas which are predominantly cropped to wheat. This may be of value should an overproduction of wheat occur. Safflower production in this area would also add a valuable oilseed meal to the adjacent range land.

Now that a commercial market for safflower seed has been established, considerable encouragement has been given to the expansion of production in the western States.

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Utilization Abstract

Drug Plants of Africa. This is the title of a 125-page booklet by Thomas S. Githens, M.D., published by the University of Pennsylvania Press as African Handbook No. 8 of the University Museum. In addition to introductory chapters on the chemical basis and utilization of drug plants it lists by common names, scientific names, geographical sources and uses over 1400 species of plants under the following categories: Plant Drugs Exported, Generic 'Synonyms, Chemical Basis of Drug Action, and Utilization of Plant Drugs.

Cinchona Cultivation in Guatemala— *A Brief Historical Review up to 1943*

The first American planting of cinchona was in 1860 in Guatemala and Jamaica. Subsequent investments in Guatemala by private and governmental agencies, negligible until stimulated by the recent war, have culminated today in plantations aggregating only about 1,000 acres with 1 3/4 million trees.

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Introduction

At first glance it seems remarkable that two hundred years should have elapsed between the discovery of cinchona (about 1630) and its adoption as a cultivated plant. But this is not so strange when we pause to recall that cinchona, in its more valuable forms, is not an easy tree to cultivate, and that there were ample supplies of wild bark to meet demands in Europe and America.

It was not until the British and Dutch undertook the development of the Asiatic tropics that the necessity for bringing cinchona into cultivation became apparent. Throughout the Indies malaria was a scourge affecting millions of people. Serious-minded investigators who visited the cinchona forests of the Andes returned to Europe stating that the supply of wild bark was dwindling, the trees in danger of complete extermination.

In 1813 Dr. Ainslie bemoaned the fact that India did not grow her own cinchona bark, a sentiment reiterated by Dr. Royce in 1835; and in Java the botanists Fritze, Miquel and others urged the introduction of the tree into that island.

The Dutch were the first to take action, but the British were not far behind. The year that Hasskarl left for the Andes (1852), efforts were made to get the British government to send out an expedition. These did not bear fruit until 1859 when Clements R. Markham was instructed to organise an exploration of all important cinchona-producing regions and bring to India planting material—seeds and young trees—of as many promising forms as possible. Thus began one of the most dramatic and important series of events in the entire history of plant introduction. The work was successful; but it remained for Charles Ledger, an Englishman living in Upper Perú (now Bolivia), to lay the foundations of the modern cinchona industry in the Far East by obtaining seeds of a superior strain from the region of Coroico in 1865.

Cinchona in Jamaica

Markham did not limit his program to India; he included Jamaica. So far as we have been able to ascertain, this was the beginning of cinchona cultivation in the American tropics. In his classic work, "Peruvian Bark" (London, 1880), Markham states that the first seeds were sent to Jamaica in 1860 and planted on the Blue Mountains near

Bath. About 1868 a further supply of seeds was sent to that island from Ceylon. The later history—and ultimate failure—of cinchona planting in Jamaica need not be recounted here.

First Attempts in Guatemala

Though Markham sent seeds to Mexico, where they were planted near Córdoba in 1872, nothing came of the effort; and we can turn our attention to Guatemala, the only tropical American country where serious attempts were made to grow cinchona in these early days.

Emili Pilli, who brought together in 1942 much documentary material regarding the history of cinchona culture in this Republic, states that Julio Rossignon was the first to plant the tree here. The date is given as 1860, the location near Cobán. Rossignon is known also for having been the first to send seeds of teosinte (*Euchlaena*) to Europe. Pilli states that Rossignon's cinchona trees received little attention and finally disappeared.

The first serious attempt to grow cinchona commercially in Guatemala seems to have been that of the Sarg family, of which we have reliable details in the memoirs of Franz Sarg, "Deutschtum in der Alta Verapaz", 1938.

Our chief interest in those early plantings is to trace the origin of the seeds employed, since it is from these seeds that many of the trees growing in the Republic have descended. Sarg states definitely that the stock used by his family was obtained from Ceylon through the good offices of Prince Nikolaus of Nassau, and that the year was 1878.

In this same year the Minister of Agriculture, Manuel Herrera, addressed a lengthy memorandum to President Justo Rufino Barrios, pointing out the advantages of cinchona cultivation and urging that the government take steps to foster the introduction and establishment of cinchona trees. In 1878 President Barrios issued a decree sponsoring the project, and offered prizes to those who would make plantings. Under the terms of this decree, the Sarg brothers received in 1882 the sum of $1,500 for their planting of 2,200 trees, which at that time were two years or more of age. Pilli states that the Alcalde of Cobán, who had these trees examined, reported that they were of two species, *Calisaya* and *succirubra.*

In connection with the taxonomy of *Cinchona*, not only in the early days but right down to the present time, the greatest caution must be exercised. Early studies suggested, and more recent investigations have amply demonstrated, that cinchonas in the wild are subject to such extreme variation—and there are so many hybrids—that specific names may mean very little.

The next step of importance seems to have been taken by the government of Guatemala which in 1883 contracted the services of W. J. Forsyth, an Englishman who had worked with cinchona in the Asiatic tropics. Under the terms of his contract, Mr. Forsyth went to Ceylon and brought back seeds with which nurseries were established in a number of places. Since the succirubras which were obtained by Richard Spruce on the slopes of Chimborazo in Ecuador were at that time being cultivated extensively in Ceylon and India, it is reasonable to believe that much of the Forsyth stock was of that strain, an assumption borne out by the appearance and the alkaloid-pattern of many trees now in Guatemala which originated in, or have descended from, the Forsyth introductions.

Pilli presents some interesting figures, as of 1884, regarding the location and extent of the Forsyth plantings. These data are of value to us in connection with the history of the material with which we are working today. Of particular importance is the planting at Finca El Porvenir, made under the direction of President Justo Rufino Barrios, who was the owner of the property and who rightfully may be called the father of cinchona cultivation in Guatemala. This honor, however, should perhaps be shared with others—notably the Sarg brothers of Coban, and Don Manuel Herrera, Minister of Agriculture.

After the death of Barrios the Reformer, cinchona culture entered a period of decline due to several factors, some of which can with difficulty be evaluated at this late day. Colombia was shipping large quantities of wild bark, much of it better in quality than that being grown in Guatemala; Java was coming into production with its fine Ledgeriana barks; prices were falling in world markets; and coffee was King.

The Beginnings of a New Era

Throughout the 1890's and the first three decades of the 1900's, cinchona cultivation in Guatemala was in the doldrums. Many of the trees which had been planted for shade in coffee fincas were destroyed. Experimental shipments of bark which were occasionally made to the United States and Europe usually resulted in loss—or at best no satisfactory profit—to the growers. The preponderance of succirubra blood in practically all of the Guatemalan trees rendered impossible any competition with Ledgeriana barks from Java.

During the first World War a serious situation developed with regard to supplies of quinine needed by the Allies. In subsequent years it was realized that an effort must be made to achieve independence of the Far East with regard to this important product.

The genesis of this effort is set forth by Frederic Rosengarten, Jr., in his "History of the Cinchona Project of Merck and Co. Inc., and Experimental Plantations Inc., 1934–1943", from which I quote the following paragraph:

"In early 1932 Merck and Co. Inc. considered the advisability of developing Cinchona in the Western Hemisphere, at the suggestion of, and in cooperation with, the State Department of the United States. It was deemed expedient to build up supplies of cinchona bark in the Americas in order to become independent of the Dutch Quinine Monopoly. It was logical that Merck and Co. Inc. should have been keenly interested in bringing cinchona cultivation back to the Americas, in view of the fact that this Company, through its predecessors, had maintained an unbroken interest in the extraction of quinine from cinchona barks since 1822, when Farr and Kunzi commenced the operation of a quinine factory in Philadelphia, two years subsequent to the isolation and identification of quinine as a crystalline compound by the French chemists Pelletier and Caventou".

After a brief and unsuccessful attempt to establish cinchona in the southern United States, Guatemala was chosen as the base for experimental work. Some of the arguments in favor of this country were the following: (*a*) it is nearer the United States than the cinchona regions of the Andes; (*b*) its government was favorably disposed toward projects of this sort; (*c*) experience of the previous century gave grounds for believing soil and climate were suitable; and (*d*) there were present in Guatemala considerable numbers of intelligent, progressive coffee planters, prepared to cooperate in the work with energy and determination.

Col. Victor E. Ruehl was delegated by Merck and Co. Inc. to undertake the organization and development of the project. He came to Guatemala in the spring of 1934 with a supply of Ledgeriana seed which had been purchased in Java. His first act was to establish close contact with the Director of Agriculture, Don Mariano Pacheco H., a man peculiarly fitted to assist because of his keen interest in new crops and his unusual ability as a plantsman.

Col. Ruehl travelled widely over the Republic, seeking out what appeared to be favorable sites for experimental plantings. He was warmly received by the finqueros (coffee planters), and shortly entered into arrangements with the late Gordon Smith of Finca Mocá near Guatalón; L. Lind Pettersen of Finca Zapote, Escuintla; Pedro G. Cofiño of Finca Retana, Antigua; and Gustavo Helmrich of Finca Samac, Cobán.

At that time, Guatemalan agriculturists had no experience with Ledgerianas—except at Finca El Porvenir where Dr. Goebel had planted a few trees. Everyone had to start from scratch. Col. Ruehl's first need was for nurserymen to propagate and grow the Java stock. He obtained from the United Fruit Company two young men trained at Lancetilla Experiment Station in Honduras: Jorge Benítez, an Ecuadorian; and Hans Franke, a German. These men were put in charge of nursery work, cooperating with the finqueros mentioned, who furnished all facilities.

Seedbeds were established at Retana, in Antigua; at Finca El Zapote; at Finca Mocá; and at Finca Samac near Cobán. In addition, some of the Java seed was left at Washington to be propagated in the greenhouses of the United States Department of Agriculture, and some was given to Don Mariano Pacheco. A small quantity was sent to Lancetilla Experiment Station in Honduras but failed to grow at that low elevation.

The seedbeds at Retana were a failure. We have since learned that Ledgeriana is not suited to that location—perhaps in part because of climate, in part because the soil is not sufficiently acid. The first plantings made at Zapote also failed because the seeds were killed, it is believed, by formalin treatment aimed to prevent the development of disease. A stand was obtained at Mocá, but it was soon observed that the plants were not doing well, and the stock was removed, in the main, to Finca Helvetia, also under the direction of Gordon Smith. Gustavo Helmrich at Coban, working alone, grew some plants and established what was, until destroyed by floods in October, 1940, one of the best plantations in Guatemala. Fortunately, before these trees were lost, many of them were propagated by grafting as well as by seed.

Don Mariano Pacheco grew a fine stock of plants which were later distributed to various places. B. Y. Morrison of the U. S. Department of Agriculture sent to Guatemala not only many plants grown from the Ruehl seed, but many others grown from seed obtained from the Philippines; from Amani, Africa; and elsewhere. Seeds from old trees near Cobán, at Helvetia, and other places in Guatemala were also planted in various nurseries.

The Kinds of Material

Before proceeding further it becomes necessary to discuss briefly the kinds of cinchonas with which we are dealing. The subject is almost hopeless if we adhere to a purely botanical classification. Ever since Weddell's time (the 1840's), the botany of the genus *Cinchona* has baffled every student. The best-known kind of cinchona, Ledgeriana, is itself so variable, and has been subject to so much crossing with other forms, that it is hard to say just what constitutes a Ledgeriana tree and what does not. Sir Frank Stockdale, in his report on cinchona culture in Java (1938), writes:

"Survivors of the original planting are still to be seen on the estate and it is clear that the seed was heterozygous as in the population raised from it many variations in habit of growth, leaf and bark characteristics are to be noticed". And elsewhere it has been stated that among these original trees, grown from Mr. Ledger's Bolivian seed, there is a range in quinine sulfate content from 3% to 13%.

And again, the wild form of *C. pubescens* or succirubra in Costa Rica contains practically no quinine; while the wild form from the slopes of Chimborazo in Ecuador (from which it is probable that most of the succirubras in cultivation have been derived) sometimes contains as much as 5%. It is therefore obvious that the agriculturist must devote little attention to the botanical classification of the material with which he works and much to its characteristics of growth and its economic value. This is made even more obligatory by the fact that much of the material in cultivation is undoubtedly the result of hybridization, often between a known pistillate and an unknown staminate parent.

At the same time, we must take notice of the botanical classification of our cinchonas because there are characteristic differences in what may be termed the alkaloid pattern of these wild forms. Thus, the Calisayas normally show a preponderance of quinine over the other principal alkaloids—cinchonine, cinchonidine and quinidine; while the succirubras do not have this preponderance; and the micranthas typically show almost no quinine at all.

Early efforts to split the genus into many species which do not always come true from seed proved hopeless from the standpoint of the practical agriculturist, as they have proved to be from that of the sound botanist. The tendency now is to recognize only a few well-defined species and admit that within each of them there are many forms of varying economic value.

In the early days of cinchona exploitation in the Andes the wild forms acquired common or trade names, and it may be well for us to follow these in part. Sir Clements Markham listed the principal wild sources of commercial bark as follows:

C. Calisaya (Bolivia and Peru) Yellow Bark or Calisaya.

C. succirubra (now called *C. pubescens*) Ecuador, etc. Red Bark.

C. micrantha (Ecuador and Peru) Gray Bark.

C. officinalis (Colombia and Ecuador) Crown Bark.

C. Pitayensis (Colombia and Ecuador) Colombian or Pitayo Bark.

Of the above species, one of the most recent students of the genus, Paul C. Standley of Chicago, recognizes only *C. officinalis*, *C. pubescens*, *C. micrantha* and *C. pitayensis*, including the Calisayas or Yellow Barks in *C. officinalis*. Certain other botanists, however, do not agree in this. The divergence of opinion is of little importance, compared with the discrepancy between some of the earlier classifications, which made 30 to 40 species of the above, and the present simplified outlook.

The Work in Guatemala Continues

The Ledgerianas planted in Guatemala in 1934 from Java seed showed many variations from the start; nevertheless there could be recognized a narrow-leaved form which was considered to be the type and which in general showed the highest content of quinine. At Finca El Zapote these narrow-leaved forms (which had come from the Washington stock, shipped down after the original seed failed to germinate in Guatemala) promptly began to die out, while the broader-leaved forms survived in small numbers and have given rise to a group of plants, considered to be hybrids, which are of strong growth and good quinine content, though not so high as some of the narrow-leaved Ledgerianas. L. Lind Pettersen took up with energy the study and propagation of these forms, and they are generally considered, at the present writing, to be some of the most promising in all Guatemala for commercial cultivation.

At Finca Mocá a few Ledgerianas which were planted in the field have done fairly well; but most of the stock which, as has been mentioned, was removed to Helvetia has done much better; and Helvetia at present has the largest planting in Guatemala of the narrow-leaved Ledgeriana forms. From Helvetia plantings were made at Finca Patzulín where also the narrow-leaved forms have done well. It is to be noted that the soils at these two places in general show a more acid reaction than those of the lands farther to the eastward on the Pacific side of Guatemala.

At Finca Panamá, Guatalón, both Owen Smith and Merck and Co., Inc. planted many Ledgeriana seedlings. Here as at Zapote the results with the narrow-leaved types have not been satisfactory, while the broad-leaved forms have done well. Only a few trees survived out of some 3,000 "Philippine Ledgers" sent down from Washington, and these were all broad-leaved forms locally considered to be hybrids.

In 1939 Merck and Co., Inc., feeling encouraged by the general progress of the project which had been able to survive in spite of a difficult financial situation among local finqueros incident to the low price of coffee in the 1930's, considered the time had arrived to expand their own activities and purchased Finca El Naranjo, above Chicacao, in the department of Suchitepéquez. The headquarters of Hans Franke and Jorge Benítez were moved to this property (they had previously been living on fincas of the cooperators, Benítez at Zapote and Franke at Helvetia); and F. C. Armstrong, an Englishman with plantation experience in the Far East, was employed as general supervisor of the work. This arrangement was terminated in May, 1940, when Wilson Popenoe was loaned by the United Fruit Co. for six months to assist in developing the project.

Earlier in 1940 B. A. Krukoff, a botanist with extensive tropical experience, had visited Guatemala on behalf of Merck and Co., Inc., and with him had come Frederic Rosengarten, Jr., who remained at Naranjo to assist in carrying out the development of extensive seedbeds at this and other places.

The year 1940 was an important one for the new industry in Guatemala. Not only were large quantities of Calisaya seed from South America planted at Naranjo, at Zapote, at Finca Panamá, at Helvetia and at Patzulín, but efforts were made to organise the experimental work along many important lines. Thus, for example, a uniform system of numbering individual trees for identification was adopted by the collaborating experimenters, after much study and effort on the part of Owen Smith, in particular. The "Individual Tree Record", prepared by Popenoe and Krukoff, was adopted, thus making possible for the first time the preservation of data in an organized form. And bark sampling, now feasible because the Ledgers grown from the Java seed had attained in some instances sufficient size to yield worthwhile specimens, was undertaken on a large scale. Particular credit should be given Mr. Rosengarten for his tireless efforts in securing and preparing bark samples from all areas, samples which were sent to Merck and Co., Inc., at Rahway, New Jersey, for analysis.

In August of this same year William Pennock, who had worked with cinchona at the U. S. Department of Agriculture's Experiment Station in Puerto Rico, was employed by Merck and Co., Inc., to undertake horticultural investigations at Naranjo. John Smith, son of Gordon P. Smith, who had returned from the Imperial College of Tropical Agriculture, Trinidad, B. W. I., took charge of cinchona experiments for the interests represented by his father, but left toward the end of the year to volunteer for military service with the Royal Canadian Air Force. His work was ably continued by Percy Davies and Harold Lewonski of Finca Helvetia.

In spite of the progress made during this year—progress along many sound lines—the young industry suffered the hardest blow yet experienced, in the death of Gordon P. Smith of Finca Mocá. Ever since the planting of the Java seeds in 1934, Gordon Smith had led and inspired the local work, and had refused to be discouraged by failures and by the difficulties through which the coffee industry had been passing. For his dogged persistence, his enthusiastic support and his willingness to cooperate at all times and in all ways, the cinchona project in Guatemala owes much to this able agriculturist whose memory will live.

At the end of 1940 Wilson Popenoe turned over the administration of the Merck interests, operated locally as Experimental Plantations, Inc., to Frederic Rosengarten, Jr., who carried forward the activities with vigor and enthusiasm. George W. Perkins, Executive Vice President of Merck and Co., Inc., and his colleague, R. P. Lukens, Director of Manufacturing (who managed the cinchona project from the Rahway end), continued to make occasional visits to Guatemala, as they had done from the start, guiding and encouraging the local cooperators. Both these gentlemen have done much to forward the work, not to mention the heavy investment of funds which they have approved with no certainty regarding the ultimate outcome.

Toward the end of 1940 Hans Franke left Naranjo, and in 1941 William Pennock left. Franke was replaced by Enrique Hoehn, a Swiss citizen with 20 years experience on coffee plantations in Guatemala, and more than usual ability as a horticulturist. Much time was devoted, on all the cooperating properties, to the care and transplanting of the Calisaya seedlings from South America, and to investigation of pressing problems. Of particular importance was grafting. It was during this year that widespread use of this method of propagation came into play, and numerous workers were trained in the necessary techniques. L. Lind Pettersen deserves great credit for taking a leading part in this; Owen Smith at Panamá, aided by Vidal Cabrera, also pushed ahead as did Finca Helvetia, the work being based largely on the pioneering in this field which had been done by Jorge Benítez.

Some of the Problems

Obviously all of this progress was not attained without encountering obstacles, nor without making mistakes. At the start there was the problem of seedbeds. Experience was lacking, and literature on the subject was not too abundant, nor were the practices therein described necessarily the best for Guatemala. The fungous disease known as "damping off" gave trouble the first year or two, but experience showed that it could be controlled through proper adjustment of ventilation and watering. Attempts to grow cuttings did not turn out satisfactorily, probably due to inexperience—at least with succirubras—since it is now known that this method of propagation is extensively used in several other regions. Budding was tried and not considered very satisfactory until results obtained at Finca El Zapote, mainly with the strong-growing hybrids, were so successful as to encourage others.

With the arrival of Ralph Pinkus at Naranjo in 1942, increased attention was given to problems of propagation at that place. Mr. Pinkus has had excellent success with the side-graft, as opposed to the veneer-graft originally used.

Data from the various centers of experimentation continued to accumulate. There was need of someone to compare growth rates, bark yields, quinine contents and disease resistance of the many clones then growing under different environmental conditions. Dr. John R. Shuman was brought from the United States to do this, and his arrival was timely, as several people who had been involved in the first experiments were gone, records were incomplete in many instances, and the burning question was, Which clones should be planted on a commercial scale?

Growth measurements were taken by thousands, laboratory analyses of bark were brought together for correlation with tree behaviour, and a detailed statistical study (in which Dr. Shuman was aided by Amado Pelén C.) was made of all this information.

It may be said that this work terminated a definite period in the development of cinchona culture in Guatemala; for just at this time the entrance of the United States into World War II threw the cinchona alkaloids into a position of great and immediate strategic importance. Programs aiming to obtain large supplies of cinchona bark in the shortest possible time were placed on foot, not only in Guatemala but also in several South American countries. The history of these projects forms a separate chapter in the romantic tale of cinchona which it is not the purpose of this brief paper to discuss, but which has already been told in part by those who participated.

Editor's Note

Dr. Popenoe's article induced the editor to ask him for some figures concerning the extent of cinchona cultivation at present in the New World. To this inquiry Dr. Popenoe replied under date of June 24, 1948:

"Merck & Co. have 600 acres at Finca El Naranjo [Guatemala]; most of the trees are at least four or five years old. They have another planting near the Mexican border, but I do not know just how large it is. There are good-sized commercial plantings of four or five private growers, and, in addition, the U. S. Government has planted a great many trees on a silvicultural basis at Finca El Porvenir [Guatemala]. I would think it safe to say that there are approximately 1,000 acres in cultivation".

Since these trees have been planted with a spacing of 4 × 4 or 5 × 5 feet, there must be about 1¾ million trees under cultivation.

Utilization Abstract

Vegetable Oils of Venezuela. In March, 1949, the Food and Agriculture Organization of the United Nations published a "Report of the FAO Oil-seed Mission for Venezuela" in which the edible oil resources of that country, consisting of twelve species of cultivated and wild palms, and seven species of other crops, are discussed in considerable detail. This report will be either abstracted or reprinted in part in subsequent issues of ECONOMIC BOTANY.

The American Peanut Industry

American production of peanuts was greatly stimulated at the beginning of the present century by the depredations of the weevil in the Cotton Belt. Apart from their use as food, their industrial utilization is only in its infancy, and includes conversion of their protein into textile fibers and other products.

C. LEWIS WRENSHALL
Director, Foremost Foundation[1]
Penney Farms, Florida

In 1947, for the sixth successive year, the farm production of peanuts in the United States exceeded two billion pounds. Although this production would make a sizeable heap of peanuts, it is not in itself remarkable, being dwarfed by our output of such farm commodities as corn, wheat and soybeans, and being only a small fraction—perhaps as little as one tenth—of the world production of peanuts.

As an article of world commerce, peanuts are valuable principally as a source of vegetable oil. The truly remarkable feature of the American peanut industry is that here peanuts are not produced primarily for oil but rather are classed as a food delicacy. Most of the American crop is eaten in one form or another by the best fed nation in the world.

Peanuts are produced to an important extent in India, China, Senegal, Manchuria, Nigeria, French Sudan, Gambia, Dutch East Indies, Japan, Spain and Argentina, as well as in the United States. In India alone the annual production runs as high as seven billion pounds. China and Manchuria together normally produce about as many peanuts as India. The United States ranks third in order of production. Britain is reported to be planning a considerable expansion of peanut production in Africa.[2]

Historical

It was long believed that the peanut was of African origin, since it spread to other countries from Africa. It is now known to be, like corn, a native of the Americas. Peanuts were grown and used as food by ancient South American Indians who placed funerary jars containing peanuts in the tombs of their dead. Some of these jars, found in a prehistoric cemetery near Lima, were decorated with replicas of peanut pods sculptured in relief, indicating the esteem in which peanuts were held by these people. While the peanut as we know it is not found growing in the wild state, about 15 wild species of *Arachis*, more or less resembling the domestic peanut, have been found in Central and South American countries. An unusual variety, with pods two to three inches long containing two very large seeds, is cultivated by the Nambyquara Indians of Rodanio, Matto Grosso, Brazil.

Probably peanuts were carried from South America to Spain and thence to

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[1] Foremost Foundation, a non-profit organization, sponsored by Foremost Dairies, Inc., Jacksonville, Florida, conducts a research program along lines of regional interest.

[2] Concerning this African peanut project, see abstract in ECONOMIC BOTANY 3: 107. 1949.

Africa by the early slave traders. Apparently they flourished in their new home and were relished as food by the natives. From Africa they were carried to the United States and other countries by the slavers who doubtless observed that the slaves arrived in good condition when fed peanuts, which were also a convenient, concentrated form of food for carrying in the holds of ships.

The Spanish peanut, a small-podded variety requiring a relatively short growing season and adaptable to diverse conditions, was introduced from Malaga, Spain, in 1871. Up to this time the peanuts grown in this country were of the larger podded types, derived from African stock. Introduction of the Spanish variety favored the wider spread of peanut culture.

In these early days the growing, harvesting, picking, and processing of peanuts were done almost exclusively by hand labor. Processing did not amount to much, as most peanuts were sold parched or roasted in the shell for out-of-hand eating. Other uses of peanuts were restricted by the large amount of hand work involved in shelling and sorting. Considerable acreage of peanuts were, however, grown for feeding hogs by "hogging off", an agreeable arrangement, still widely practiced, whereby the soil is enriched and the hogs do the work of digging and picking, fattening for market in the process. It is said that peanut feeding results in soft pork, while others maintain that it imparts a delectable flavor to the hams.

The rise of the modern American peanut industry dates from the development, in the 1870's, of machinery for picking, cleaning and shelling peanuts. Cleaning plants were established in New York City and Norfolk, Virginia, in 1876. In the succeeding years other plants were erected, and at the turn of the century the Virginia-North Carolina area, then the only important producing district, was well supplied with cleaning and shelling factories.

The spread of peanuts to other areas of the South was greatly influenced by a major disaster which befell southern agriculturalists. This was the incidence of the cotton boll weevil in such serious proportions as to cause many farmers in the Cotton Belt to turn to other crops. First in Texas and later, as the boll weevil swept eastward, in Alabama, Georgia and Florida, the growing of Spanish peanuts in place of cotton became prevalent. In the southeastern section the Runner type of peanut, probably derived from the Wilmington or African variety, became important. Peanut farming was so successful in some sections that farmers came to regard the boll weevil as a blessing in disguise. Indeed, Enterprise, Alabama, which became the center of a thriving peanut-farming area, erected a monument to the boll weevil.

As the growing of peanuts spread, modern cleaning and shelling plants sprang up throughout the South. Beginning in Texas in the early 1900's the industry continued to grow, spreading eastward until peanuts were being shelled in plants throughout the Southeast, and many of the oil mills were crushing peanuts as well as cottonseed. Throughout the First World War there was a veritable boom in peanuts.

In the years following the First World War the prices for peanuts and other farm products declined, and practical measures for controlling the boll weevil came into general use. The acreage planted to peanuts fluctuated considerably, and many areas where peanuts had been grown reverted to other crops. Peanut production settled down to three rather well defined areas, the Virginia-North Carolina area, the southeastern or Georgia-Florida-Alabama area, and the Southwestern or Texas-Oklahoma area.

The long term trend has been toward steadily increased consumption of peanuts. Disregarding annual fluctuations, the per capita consumption has increased from about four pounds in 1919 to almost seven pounds in 1939. Since 1929 the rise in consumption has been relatively steady. With the advent of World War II, consumption jumped sharply, exceeding 11 pounds per capita in 1944 and 1945. It is thus clear that peanuts are to be classed among the staple foods in the American diet.

Food Uses and Food Value

The popularity of peanuts as an American food staple is in many ways a puzzling phenomenon. It would seem that the lowly goober provided at first merely an acceptable substitute for the more expensive and less accessible varieties of nut. In the early days most commercial peanuts were sold roasted in the shell for out of hand eating. In this form they proved popular also with monkeys and elephants. The association of peanuts in the shell with baseball games, carnivals, zoos and circuses continues to this day and in the minds of many people constitutes the chief use for peanuts.

With the advent of a machine-shelled product the tastier salted peanut made its appearance and soon gained wide popularity. Candy manufacturers, too, turned to shelled peanuts for the nut ingredient of their wares. Consumption of peanuts in these forms soon far exceeded that of peanuts in the shell.

It remained for peanut butter, however, to provide the greatest single outlet for peanut as food. After a slow start as a "health food" this simple product—essentially just ground roasted peanuts with salt—has in recent years accounted for about as many peanuts as all other food uses combined.

Although it may be doubted that it has had much to do with stimulating consumption, the fact is that, from the point of view of nutrition, the peanut is almost in a class by itself amongst low priced food products. It is, in the first place, about as concentrated a food as money can buy. One gram supplies 5.8 food calories. This compares with 4 calories per gram for sugar, 3.5 calories for whole wheat, 2.6 calories for bread, 2.3 calories for beefsteak, and so forth. The high calorific value of the peanut is due to its low moisture content—about one percent in roasted forms such as peanut butter—and its high content of oil which makes up approximately 50 percent of the kernel.

The peanut kernel as a whole is highly digestible. The principal constituents are oil, protein and carbohydrate, in that order. The oil is almost completely digestible and ranks with butterfat in food value if vitamin-A content is not taken into consideration. Peanut protein also is highly digestible, either raw or cooked. In fact, there seems to be no reasonable basis for the prejudice against eating raw peanuts. The carbohydrates present are principally ordinary sugar and starch, but the total content is relatively low, making the peanut suitable for use in low-carbohydrate diets.

The peanut's principal claim to nutritional fame lies in its rich content of high quality protein. Vegetable proteins in general are less valuable foods than the animal proteins. The biological value of peanut protein is among the highest of the vegetable proteins and has been reported to be almost equivalent to that of casein. Furthermore, the composition of peanut protein is such as to supplement the deficiencies of the cereal proteins—a good argument for the use of peanut butter. Because it is such an excellent protein source, the peanut compares favorably in food value with more expensive foods of animal origin.

Peanuts are rich in some vitamins, almost wholly lacking in others. In general, the members of the B complex, especially thiamin, riboflavin and nicotinic acid, are present in important amounts. Peanuts are also a good source of vitamin E, but vitamins A, C and D are not present in appreciable amounts. Recent work, as yet unpublished, sponsored by the National Peanut Council at Southern Research Institute, shows peanut foods to be good sources of folic acid, a B vitamin which is now known to play an important role in the prevention and cure of pernicious anemia.

With regard to minerals, phosphorus, calcium and iron are present in significant amounts, while the presence of a number of the so-called "trace elements", such as copper and zinc, has been detected spectroscopically.

From a nutritional point of view there seem to be excellent reasons why peanuts should continue to grow in favor as food.

Peanut Culture

Peanut farming is fraught with problems and difficulties, some of which are the result of the unusual growth habit of the peanut plant, especially the bearing of the fruits underground, while others are related to what might be called the physiological peculiarities of peanuts. In the opinion of many, these drawbacks have been largely responsible for limiting the development of the peanut industry. In fact, considering the potential usefulness of peanuts in both food and industrial fields, it is not too much to say that the future of the industry depends to a great extent upon finding practical solutions to the problems of peanut culture.

Whether or not the peanut should really be called a "nut" at all is perhaps a debatable point. Certainly the name is predicated on the nutty character of the fruit rather than on botanical considerations.

The peanut plant bears many resemblances to other common legumes, such as peas and beans, to which it is, in fact, closely related botanically. If only its fruits, like those of its cousins, were found dangling conveniently in the air,

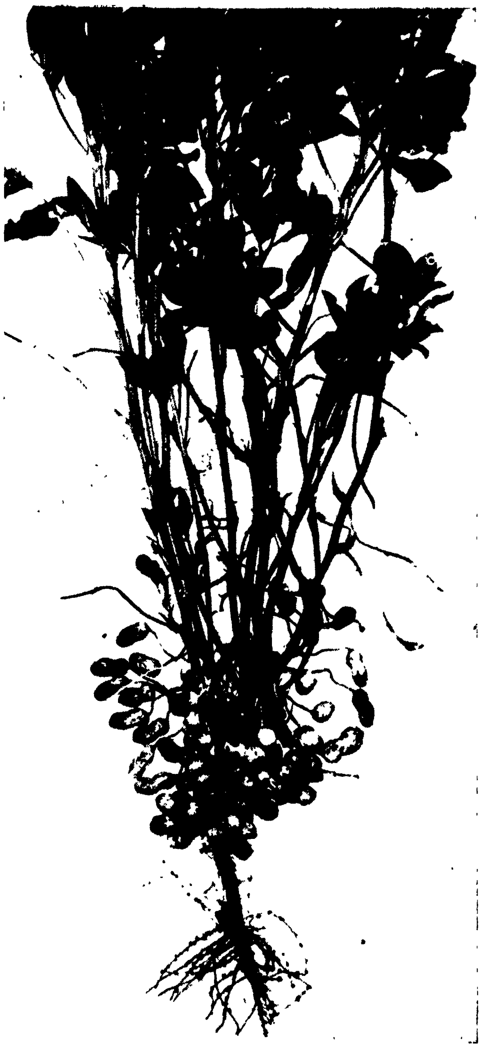

FIG. 1. Spanish peanut plant. Note upright habit, fruits attached to stems but closely grouped around base, separate root system with main tap root and well nodulated branch roots. (*Courtesy Ga. Agr. Exp. Sta.*)

not only would the resemblance be complete but its culture would be greatly simplified. It may even be doubted that the worthy soybean would ever have stood a chance against such a competitor.

It is a common misconception that the peanuts grow on the roots of the plant. This, of course, is entirely erroneous, since the flowers from which the fruits develop are borne in the leaf axils in quite orthodox fashion. Following fertilization the sessile flower, including the peduncle-like tubular calyx, withers and drops off, leaving no trace of its passing visible to the unaided eye. The fertilized ovary lies embedded in the axil awaiting some obscure signal to call forth the next stage of its development. This next stage is the emergence of the "peg", a tendril-like process, bearing the fertilized ovary at its tip. It grows out and down, forcing its way an inch or two into the soil where finally the seed pod and seeds develop.

Sometimes the peg develops immediately after the flower drops, but it is common for peg emergence to be delayed for days or weeks, and commonest of all for it never to emerge at all. Little is known of the forces and factors governing this phenomenon. It is apparent, at any rate, that only a fraction of the peanut plant's potential productive capacity is realized.

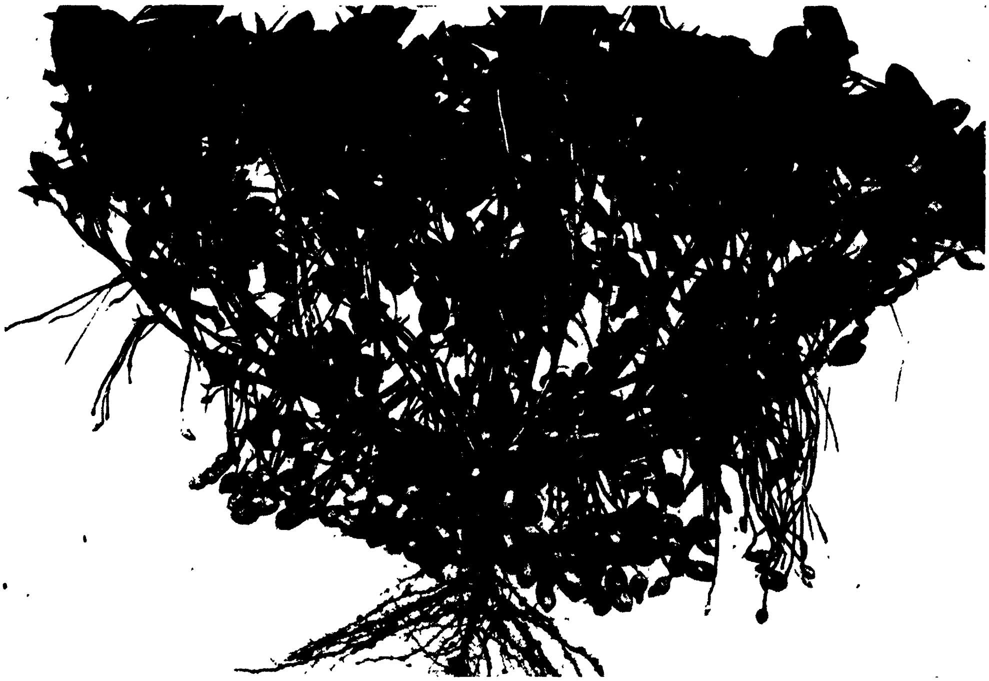

FIG. 2. Runner peanut plant. Note attachment of fruits to prostrate sections of stem branches, also many undeveloped pegs and partly developed fruits. (*Courtesy Ga. Agr. Exp. Sta.*)

The "pegging down" of the peanut plant, as this stage of development is commonly called, cannot readily take place if the soil is resistant to the entry of the peg. Hence, a prime requirement for growing peanuts is a friable, loose-textured soil. Most peanuts are grown in the sandy soils of the coastal plains area. Another limitation imposed by this growth habit is that subsequent cultivation must be conducted with due care to avoid disturbing the pegs. This is especially true with the runner type plants which become "pegged down" along a considerable length of the prostrate stem branches.

Nor is the production of peanuts assured by the fact that numerous pegs are sent down into the soil. Development may be arrested at any stage thereafter. Sometimes the pod or shell develops normally but no seeds are produced in it, resulting in what is known as a "pop". The truly strange thing about this is that the developing fruits seem to have their own nutrient requirements, separate from the peanut plant as a whole. Many years ago it was observed that there are root hairs on the peanut hull, indicating that the pods themselves take up nutrients from the soil. Recent work by scientists in both North Carolina and Florida has confirmed that this is so. Apparently proper fruiting depends not so much on the elements available to the plant roots as on the nutrient status of the fruiting zone. Most important is an adequate supply of available calcium in the soil surrounding the developing peanuts. The large podded Virginia types are much more exacting in their calcium requirements. These findings seem to provide ample justification for the practice, long common in Virginia and North Carolina, of dusting the fields with land plaster (gypsum), a source of readily available calcium, about the time pegging down is taking place.

Blossoming of the peanut plant continues over a considerable period, and the same is true to an even greater extent of pegging down. During periods unfavorable to growth, pegging down may be almost completely arrested, to be resumed when favorable conditions again prevail. Thus it cannot be said at any time that a peanut crop is ripe or mature. The farmer aims to harvest the crop when the largest yield of sound nuts will be obtained, but some immature nuts are invariably present, while waiting too long invites deterioration of the fruits that were earliest set.

It is in the harvesting operations that the disadvantages of the peanuts' subterranean development are most apparent. The plants must be ploughed out, or the equivalent, with correspondingly high consumption of mule, horse or tractor power. They must then be shaken free of adhering soil. Since the fresh-dug nuts have a high moisture content, they must be thoroughly dried before they can pass into commercial channels. Curing in the field may take from a few days to several weeks, depending on weather conditions, after which it is still necessary to pick or thresh the nuts from the vines and haul them to market.

Harvesting peanuts in the traditional manner is thus an extremely laborious, long-drawn-out undertaking and one which does not readily lend itself to mechanization by conventional means. Hand labor is still used extensively in shaking, stacking and picking operations. While this may not be a serious impediment to success in countries having abundant cheap labor, under present American conditions it makes peanut production very expensive and prices the product out of the market for many potential uses. An acute need is felt, therefore, for cheaper mechanical methods of peanut harvesting.

While it is obvious that peanut harvesting can never be so simple and direct as the combining of grain crops, recent developments have clearly demonstrated that revolutionary improvements are possible and, indeed, almost within reach at this time. Primary importance can be attached to recent work in Georgia which disproves some of the traditional ideas concerning peanut harvesting. It has been shown that rapid curing is in no way detrimental to quality and that it is not necessary for the nut to be attached to the plant during the curing process. Also demonstrated was

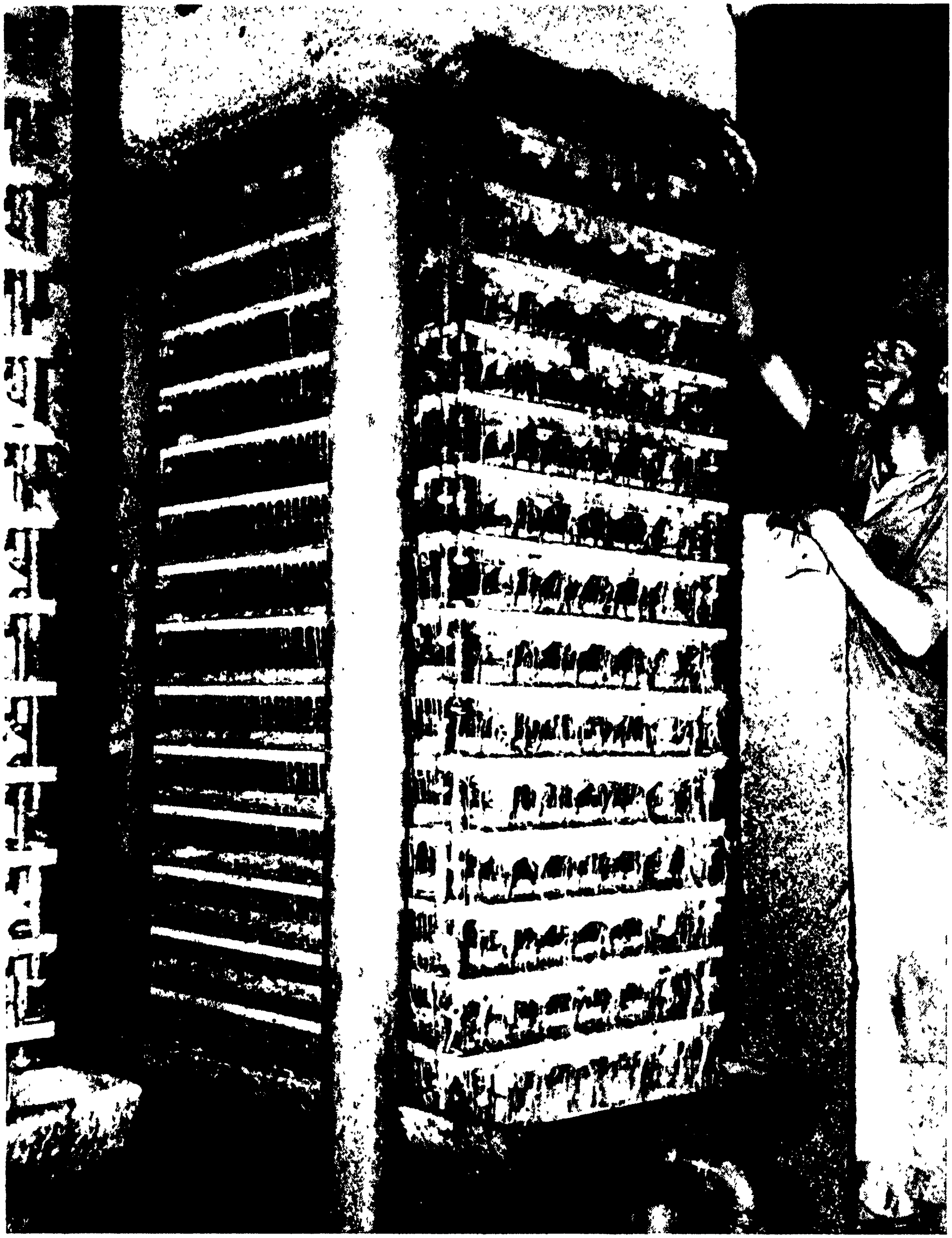

FIG. 3. Peanut oil flowing from plates of a hydraulic press in typical crushing operation. (*Courtesy Stevens Industries, Inc., Daw on, Ga.*)

the feasibility of harvesting the vines separate from the nuts, thus paving the way for the production of high quality peanut hay, practically the equivalent of alfalfa hay.

Other significant advances made in recent years are the development of a two row digger-shaker-windrower by the U. S. Dept. Agri., Soil Tillage Laboratory at Auburn, Alabama, and the experimental use by the Texas Agricultural Experiment Station of a combined harvester for picking up and threshing the nuts after curing in the windrow. Use of the side-delivery rake for windrowing has been practiced in the Southwest for a number of years. Windrow curing has a much better chance of succeeding in the climate of the southwestern producing area. In threshing the crop by the combined harvester the vines are returned to the soil, becoming a favorable factor in conserving fertility.

The ultimate in mechanization would appear to be to dig, shake and pick the nuts in one operation. The vines could either be harvested separately beforehand and handled as a high quality product, or returned to the soil for fertility maintenance at the option of the grower. Such a system would necessitate curing the nuts in the form of green farmer's stock. Now that the fundamental objections to such a practice have been negated by the Georgia results, it remains only to work out practical methods of accomplishing the result. More difficult problems have been solved.

Although it is a legume, the peanut can hardly be regarded as a soil-building crop. Especially when harvested for both hay and nuts it removes large quantities of nutrients from the soil. It has, moreover, unusual ability to feed on the less available nutrients in the soil. Consequently it is soil-depleting and at the same time indifferent to fertilization. After several crops of peanuts have been grown, other crops are likely to show acute symptoms of potash deficiency. Peanuts, however, do not usually respond favorably to potash fertilization. It is abundantly clear that the peanut is highly individualistic in its nutrient requirements. Its peculiarities in this regard doubtless account in some measure for the fact that per acre yields have not changed materially over a period of many years.

The peanut is about normal in its susceptibility to diseases and pests. However, special mention should be made of the so-called "concealed damage" that has been attacking the Southeastern Runners in recent years. Concealed damage is caused by growth of mold, principally between the two halves of the kernel, but to such a slight extent that no deterioration is apparent on superficial examination. The damage shows up when the nuts are roasted, the affected kernels turning dark on application of heat. The presence of appreciable amounts of concealed damage therefore causes down grading of Farmers' Stock.

There is some evidence that concealed damage is caused by a specific organism. The incidence of damage is greatly affected by weather conditions during curing. Rapid curing would probably prove to be an effective control measure. Attempts to develop varieties resistant to this disease are also meeting with considerable success.

Primary Processing

After the peanuts have been grown, harvested and picked or threshed, they are ready to start through trade channels to the ultimate consumer. At this stage they are known as "Farmers' Stock" and are delivered to the primary processors either in bulk or in large burlap bags.

Farmers' Stock is bought according to grade standards published by the U.

S. Dept. of Agriculture. Factors such as moisture content, proportion of dirt and trash present, shelling percentage, concealed damage and size of nuts are taken into account in grading. The grade determines not only the value of the nuts but also whether they can enter edible channels or must be crushed for oil and meal. Sometimes the stock must be dried before it can be stored safely.

Farmers' Stock invariably contains a considerable amount of dirt and trash, such as small stones, stem fragments and mud balls. The first step in processing is to separate as much as possible of this debris from the nuts by means of dirt reels and an array of sieves, blowers and shakers. Despite every effort at this stage some foreign material escapes removal and becomes evident in later processing. The earthy origin of the peanut is probably the cause of more "headaches" than any other single factor in the industry.

When peanuts are to be sold for roasting in the shell the entire process may consist of thorough cleaning and screening for size, and then powdering by rolling with talc in large drums. Usually only jumbo Virginia nuts, grown on light-colored sandy soils to avoid serious discoloration of the shells, are used for this purpose. The powdering process helps to give the shells a uniform light color.

By far the larger proportion of nuts entering the food trade does so as shelled stock. To produce shelled stock ingeni-

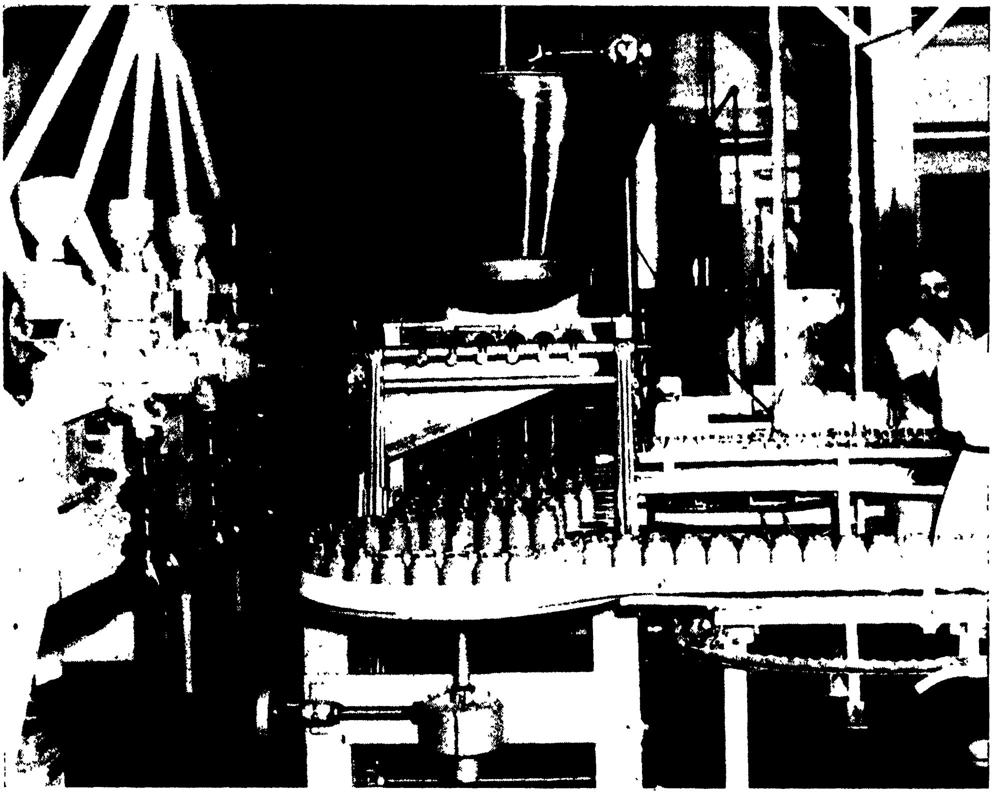

FIG. 4. Automatic filling operation in large scale production of peanut butter. (*Courtesy Cinderella Foods, Dawson, Ga.*)

ous machines break off the hulls so far as possible without removing the red skins or damaging the kernels in any way. The meats are then separated from the broken shells by shaker sieves and blowers. The kernels are sifted to remove splits and shrivels and finally pass over picking tables for the removal of damaged nuts and debris that have escaped mechanical removal. The resulting shelled stock must conform to U. S. grading standards. The splits, shrivels and damaged nuts are relegated to crushing.

When Farmers' Stock does not meet the requirements for food uses, after preliminary cleaning it is shelled and crushed for oil and meal. In this case shelling is not a critical operation, since it makes no difference if the nuts are broken. A proportion of shell material is admitted to the crushing stock to promote oil removal and to standardize the protein content of the resulting press cake meal.

The crushing stock is ground up in a suitable mill and then subjected to a cooking process before the oil is expressed. Most peanut crushing is done with hydraulic plate presses which are also widely used in cottonseed crushing. Recently the more efficient expeller presses are coming into more general use. Solvent extraction has not yet found widespread use in the peanut industry.

Few peanut crushers have facilities for refining the oil they produce. It is usually sold as crude peanut oil to large scale vegetable oil processors to be refined, bleached and deodorized, thereby losing its identity as peanut oil. Relatively little peanut oil reaches the consumer as such. Most of it goes into the manufacture of shortening and oleomargarine where it is used interchangeably with other similarly refined vegetable oils.

The press cake which is the byproduct of peanut crushing is ground to a fine meal and sold as a protein concentrate to manufacturers of mixed feed.

Food Processing

The processing of peanuts for food use involves blanching to remove the skins and some form of roasting or cooking. When whole nuts are required in the end product, as, for example, for whole salted nuts, the process is a delicate one called "whole nut blanching". The peanuts must be lightly roasted to loosen the skins and then run through a machine which gently rubs off the skins without exerting enough pressure to cause the nut to split. When whole kernels are not required the nuts are handled rapidly by a split nut blancher. They pass between belts travelling at different speeds which rub off the skins, at the same time splitting the kernels and freeing the hearts. This type of blancher is used in peanut butter manufacture.

In making salted peanuts it is usual to cook the peanuts in vegetable oil. The batch of nuts is placed in a perforated metal basket, lowered into a vat and literally "boiled in oil" until cooked to the desired degree. The basket is then raised out of the oil and allowed to drain. The nuts are dumped into bins with perforated bottoms and cooled rapidly by drawing air through them. The required amount of salt is then mixed with each batch. Prompt packaging in air-tight containers is of the greatest importance in preserving freshness.

Dry roasting is also a batch operation. Roasters are usually gas-fired. The batch of nuts—from 100 to 500 pounds, depending on the capacity of the roaster—is placed in the rotating cylinder and cooked until the desired color is attained. Whole nut blanching requires a light or "white" roast, whereas for peanut butter a heavy or "brown" roast is customary. Roasters of recent design have thermostatic control and automatic cutoff when the desired degree of roast has been attained.

Peanut butter is essentially ground roast peanuts with added salt. After roasting to the desired brown color the skins and hearts are removed and the split kernels are ground to the desired degree of fineness by passing through a mill. The required amount of salt is metered in as the nuts are delivered to the grinder. Many manufacturers also introduce one to two percent of hydrogenated vegetable oil at this point to retard separation of oil in the finished product. In some cases other ingredients are added, and additional processing may be given with the object of producing a more or less homogeneous butter.

Peanuts in one form or another enter into the composition of an almost endless variety of confectionery, and it is beyond the scope of this article to discuss the numerous processes involved in the manufacture of these familiar products. However, one operation may be mentioned which is recurrent in every stage of handling peanuts, and that is the use of the picking table to remove defective kernels and extraneous material. Electric sorting machines have found limited application, but most of this work is done by hand.

Industrial Uses

Walter Winchell and numerous other journalists to the contrary notwithstanding, the late Dr. George W. Carver of Tuskegee Institute did not establish a large number of industrial uses for peanuts[1]. As a matter of fact, peanut products do not at present enter into industrial uses to any important extent.

In an earlier publication[2] we reviewed the possibilities for industrial utilization in considerable detail and concluded that some products derived from peanuts have distinct possibilities as industrial raw materials. A very considerable body of technical information on industrial uses has been amassed, largely through the efforts of the Southern Regional Research Laboratory. In a further discussion it was brought out that the high cost of producing peanuts is the most serious obstacle to industrial utilization. Thus the wide scale industrial utilization of peanuts depends to a large extent on agricultural developments leading to cheaper production.

It is thought that products made from peanut protein offer the most promising possibilities for industrial development. The manufacture of textile fiber appears to be of particular interest at the present time, and adhesives, sizes, coatings, *etc.* are recognized possibilities. Plans for commercial scale production of peanut protein textile fibers by an American concern were recently announced. In Britain development of a textile fiber was announced several years ago, and the product was introduced to the trade under the name "Ardil". Since other cheaper proteins are available, it is evident that peanut protein must have properties that make it especially desirable for textile fibers.

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[1] This is a plain statement of fact that is not intended to detract from Dr. Carver's reputation. According to the testimony of his colleagues, Dr. Carver's life was devoted to the task of elevating the standard of living of his people by showing them what could be done with the materials at hand. It seems doubtful that he was even interested in industrial developments. He was as much craftsman as scientist, perhaps more farmer than either. One of his chief concerns was to make his people aware of the value of keeping a cow on the farm. His published contributions on the subject of peanuts were only two:

"How to grow the peanut and 105 ways of preparing it for human consumption". By G. W. Carver. Bulletin 31, Tuskegee Institute. This is a brief treatise on peanut culture, followed by 105 home-kitchen recipes involving the use of peanuts.

"The Peanut". By G. W. Carver and A. W. Curtis, Jr. Bulletin 44, Tuskegee Institute. This is a treatise on peanut culture.

[2] See abstract of this in ECONOMIC BOTANY 1: 115. 1947.

Outlook

Any attempt to appraise the future of the peanut industry must necessarily be highly speculative. The position of peanuts in America is unique in that our peanut industry is essentially a food industry. In the writer's opinion the food possibilities of peanuts have not yet been fully explored or exploited.

The great nutritional value of peanuts, particularly for the supplementation of cereal foods, makes logical a tremendous expansion of the use of peanut flour or some type of peanut meal. So far the production of edible peanut flour is relatively insignificant. Recently the use of whole peanut meal in making nutritionally superior corn muffins, pancakes, *etc.* has been demonstrated. Commercial production of whole peanut meal is feasible and may provide a new food outlet for peanuts. Another recent experimental development with interesting possibilities is the use of peanuts as the basis for frozen desserts.

It is felt that no large scale industrial utilization can be anticipated until the cost of peanut production can be brought down to such a level as to assure stable supply in a price range that will provide profit to both grower and manufacturer. Industrial uses are not likely to be based on surplus production. However, as has been pointed out repeatedly, the possibilities for industrial utilization do exist if the required balance of economic factors can be attained.

In the face of these long range possibilities, the current crop of peanuts is large and prices are supported at relatively high levels. Thus the industry is confronted with the paradoxical situation of having a surplus while prices are so high as to restrict sales and inhibit the development of new products. Doubtless considerable readjustment of economic factors must be witnessed before a clear picture can be formed of the industry's ultimate potentialities.

Utilization Abstract

Pecan By-products. In the pecan-shelling industry of the South there is a spread of about 3% between the actual meat content of pecans and the amount of salable meat recovered. Since 1943 J. R. Fleming and Co. has been extracting oil from this previously wasted portion and is now processing this fraction from about 90% of all the pecan-shelling plants on the west of the Mississippi River. About 90% of the production is being consumed by the drug and essential oil trade. The Company is also producing about 100,000 pounds of tannin weekly from the shells, some of which is going into the tanning industry, another portion into "drilling mud". Ground pecan shells have been used also in the plastics industry, for "sand-blasting" machinery and airplane engines, and for cleaning raw furs. (J. R. Fleming, *Chemurgic Digest 8(5): 25. 1949*).

Production and Utilization of Alfalfa

Alfalfa, the most important forage crop grown in the United States, is harvested in this country from 15 million acres, and in the 1946–1947 season yielded 34 million tons of hay used principally for feeding stock. About 700,000 tons of alfalfa meal are used in mixed feeds, primarily for poultry, and also serve as a source for extraction of carotene, chlorophyll and xanthophyll.

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History

THE ancient Greeks and Romans were well aware of the value of alfalfa. Cato (B.C. 234–149) in "De Agricultura" wrote of the use of legumes to improve the soil, and Varro (B.C. 116–27) gave some excellent advice on the seeding of alfalfa. The Greek Amphilochus is said to have written an entire book on alfalfa, and agriculturists of that early period were evidently aware of many of the merits of this crop. Columella (A.D. 60) pointed out the superior advantages of alfalfa, such as its long life, the fact that it can be mowed frequently, its beneficial effect on soil, its value as a feed for cattle and horses, and he gave good advice on methods of cultivation.

Hendry (15) has written of the history of alfalfa and has cited sources. According to his account, "Alfalfa probably originated in Mesopotamia and proceeded from there southward into Arabia. The word "alfalfa" is Arabicised Persian, derived from the Iranian word "aspasti", and is traceable to the old Iranian word "aspo-asti" (to eat) and literally means "horse fodder".

According to Pliny, alfalfa was introduced into Greece upon the invasion of that country by the Macedonians and Persians. The plant was named "medic", and this name is retained in the present botanical name, "Medicago". The term "lucerne", often used in Europe, probably is derived from the prominence of its early culture in the Lake Lucerne area of Switzerland, from which it spread throughout northern Europe. Alfalfa was carried to the New World by the Spaniards and became established in the 16th century in Peru and Chile.

George Washington and Thomas Jefferson both grew alfalfa during the Colonial period (2). The two most important introductions from the standpoint of present culture were the introduction in Minnesota in 1857 by Wendell Grimm, of alfalfa brought from the Grand Duchy of Baden, Germany, and the introduction of the Chilean variety in California during the Gold Rush period, 1849–51. W. A. Cameron of Marysville, California, is reported to have produced alfalfa from Chilean seed in 1851. The alfalfa grew so well in the warm and fertile valleys of California that for a time it was known as "California clover".

By constant selection of seed, Grimm was able to develop increased cold resistance in his alfalfa, so that when the importance of varietal differences began to be appreciated, some 50 years later, this northern strain formed one of the parents for present-day commercial varieties.

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[1] Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

Taxonomy

The genus *Medicago*, of the large group of Leguminosae, contains about 50 species, of which the purple-flowered alfalfa, *Medicago sativa* L., is most important. Crosses between *Medicago sativa* and *M. falcata*, a Siberian species, are sometimes called variegated alfalfas, and classified as *M. media*. There are several other species which are of importance chiefly because of their possible usefulness for the production of hybrids. One of these, *M. tunetana*, is of Mediterranean origin, and because it propagates readily by means of rhizomes, it may become of importance for pasture forage in the South. There are over 1,000 strains of alfalfa, and the possibil'ties of plant improvement have just begun to be appreciated.

Breeding

The American Breeders Association (2) reports no deliberate breeding of alfalfa previous to 1903. At the time of that report, 1909, eleven workers were stated as directly interested in alfalfa improvement. Yield, quality and winter resistance were the main objectives of early workers; resistance to disease and plant pests had not become of major significance in the breeding program.

Tysdal and Westover (22) present an excellent review of alfalfa work to 1937. They list the following objectives as being mentioned in reply to a questionnaire sent to all known alfalfa workers (figures in brackets indicate the number of times mentioned in 23 replies): increased seed setting capacity (10); higher yield of quality forage (8); winter hardiness (8); disease resistance (8); suitability for grazing (5); adaptation to different soil conditions (4); resistance to heaving injury (2); resistance to drought (2); insect resistance (2); increased resistance to drought (2); increase in protein content and leaf percentage (2); a type less susceptible to injury from early leaf cutting (1); larger seed (1).

Increase of bacterial wilt disease, stem nematode infestation and leaf-spot diseases has focused attention on the development of improved disease-resistant varieties of alfalfa. Wilt-resistant strains were found in Turkistan, and by crossing with Grimm and Common, wilt resistance was combined with yield and quality characteristics necessary for farm use. Two recently developed varieties are Ranger and Buffalo. Ranger is a cross of Turkistan, Cossack and Ladak, and is recommended for the more northern States where bacterial wilt is serious. Buffalo is an adaptation of Kansas Common, with increased wilt resistance. Other recent introductions include Atlantic, produced for east coast conditions by plant breeders at the New Jersey Agricultural Experiment Station, and Nemastan, a variety found by the Utah and Nevada Agricultural Experiment Stations to resist stem nematode infestation. In the more southern States where wilt is not widespread and cold resistance is less important, Peruvian strains are successful.

Hybrid alfalfas offer promise of even better yields and disease resistance than has hitherto been possible (23, 24). In tests at the Nebraska Agricultural Experiment Station, hybrids yielded 20–27 percent more than Grimm.

Production

Alfalfa is grown in all parts of the United States, but of the 15 million acres in this crop, by far the greatest concentration occurs in the widwestern and western States. Michigan and California both had over one million acres in production in 1946, and Nebraska, Minnesota, Kansas, Wisconsin, Idaho, Montana and Iowa each harvested over 700,000 acres (26). Approximately one-fifth of the 75,000,000 acres in hay is in alfalfa and in terms of tonnage alfalfa accounts for one-third of the 100-million-ton annual hay crop.

Alfalfa prefers well-drained calcareous loam and does poorly on tight, wet or acid soils. It needs plenty of room for its roots, and a shallow or fluctuating water table at a depth of four feet or less will tend to drown out the stand. On the other hand, in the Platte River Valley in Nebraska alfalfa does very well with a water table of six to twelve feet, and most weeds are rapidly eliminated because of failure of their roots to reach water.

A firm seedbed of good tilth with plenty of soil moisture is required for germination. Shallow seeding is desirable. Caking or baking of surface soil will prevent emergence of the young plants. Young stands that have not established a deep root system are sensitive to drought and to soil temperatures. Planting is customary in the spring and early summer. A nurse crop of wheat or other grain sometimes is sown with the alfalfa. Where high temperatures and drought are apt to occur, as in Kansas, southern California and south-

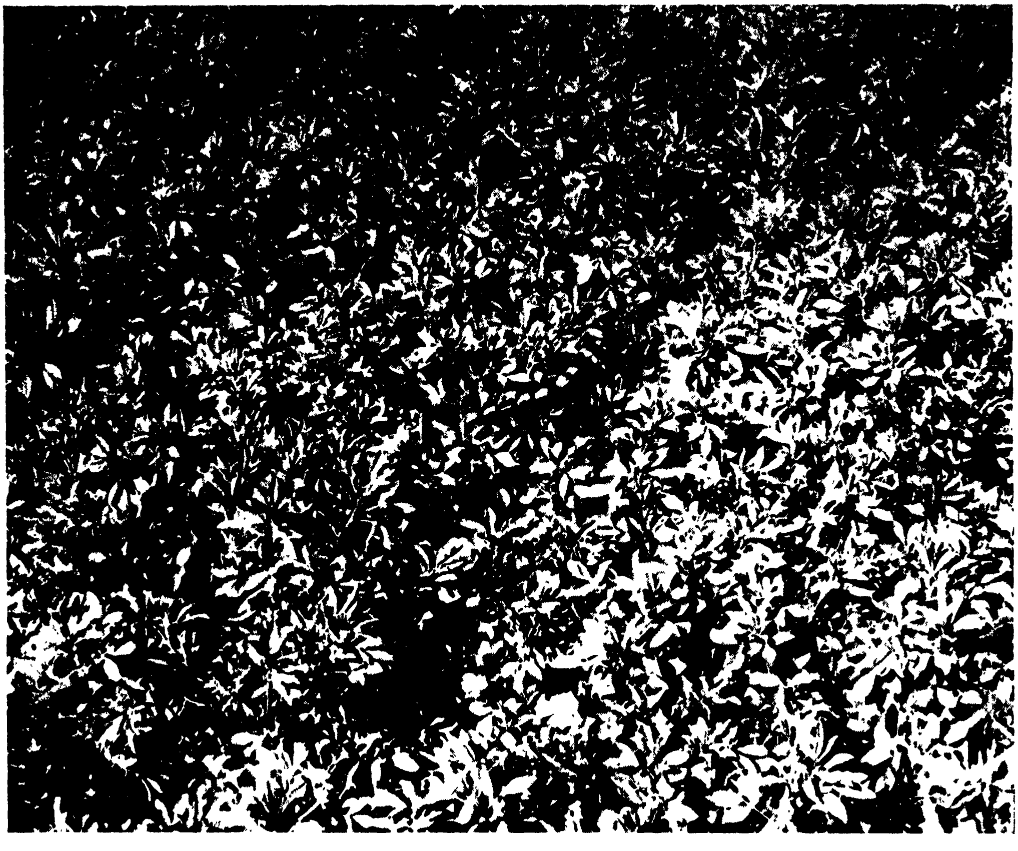


FIG. 1. Alfalfa, as it appears in a cultivated field. *(Courtesy U. S. Dept. Agr.).*

ern Texas, fall or winter planting is necessary so that a stand is sufficiently established to resist summer conditions.

The amount of seed sown per acre varies in different localities, but under reasonably favorable conditions, 20 pounds is ample to establish a good stand. Some alfalfa producers, especially those who are manufacturing alfalfa meal, favor a heavier seeding of 30 to 50 pounds per acre. They believe that they get more meal from the first two cuttings and that the thicker stand produces thinner-stemmed plants with a higher proportion of leaves. Since 60–80 percent of the protein in the plant is associated with the leaves, leafiness is important. Seeding from airplanes is becoming a standard practice in California.

In areas where alfalfa or legumes have not previously been grown, seed inoculation is desirable to insure nodule formation and nitrogen fixation by the symbiotic bacteria associated with the roots.

Alfalfa meal or hay contains approximately 10 percent ash. Each five tons of annual crop means the removal of 1,000 pounds of soil minerals. The necessity for available minerals is shown in Table 1, which lists the amount and composition of alfalfa ash.

Because of this high ash content and removal of a high proportion of available minerals, adequate potash, lime and phosphate are necessary for maximum yields. Experiments in southern Idaho (21) resulted in almost doubling the yield of alfalfa when yearly applications of treble superphosphate were made during the first three years of a six-year rotation of alfalfa for three years, potatoes for two, and wheat for one year.

Where the soil is low in available phosphorus, Idaho authorities recommend two or three applications of treble superphosphate at the rate of about 300 pounds an acre. High phosphorus levels in the soil resulted in a higher level of phosphorus in the hay (0.180 percent; control, 0.138 percent) and a yield of 5⅓ tons as against a control yield of three tons per acre. In certain areas 20 or 30 pounds of borax per acre have increased alfalfa yields 50 to 60 per cent (17). Alfalfa pastures usually respond to applications of manure and organic fertilizers.

Because it is a nitrogen-fixing legume and also because of the soil depths from which it draws nutrients, alfalfa is not regarded as a soil-depleting crop. This premise is open to question when the crop is grown intensively for cutting and no relief is provided by pasturing, fertilization or crop rotation. Schreiner and Brown (18) list alfalfa as removing 190 pounds of nitrogen for each four-ton-per-acre yield. Fifteen tons of sugar beets together with tops remove 118 pounds, and a 65-bushel-per-acre corn crop takes out 96 pounds per acre. However, these latter crops do not replace any of the nitrogen as does alfalfa. California investigators estimate that a stand of alfalfa will raise the nitrogen level in soils by 60 to 80 pounds per acre per year, and this increased fertility is confirmed by the increased yield of

TABLE 1

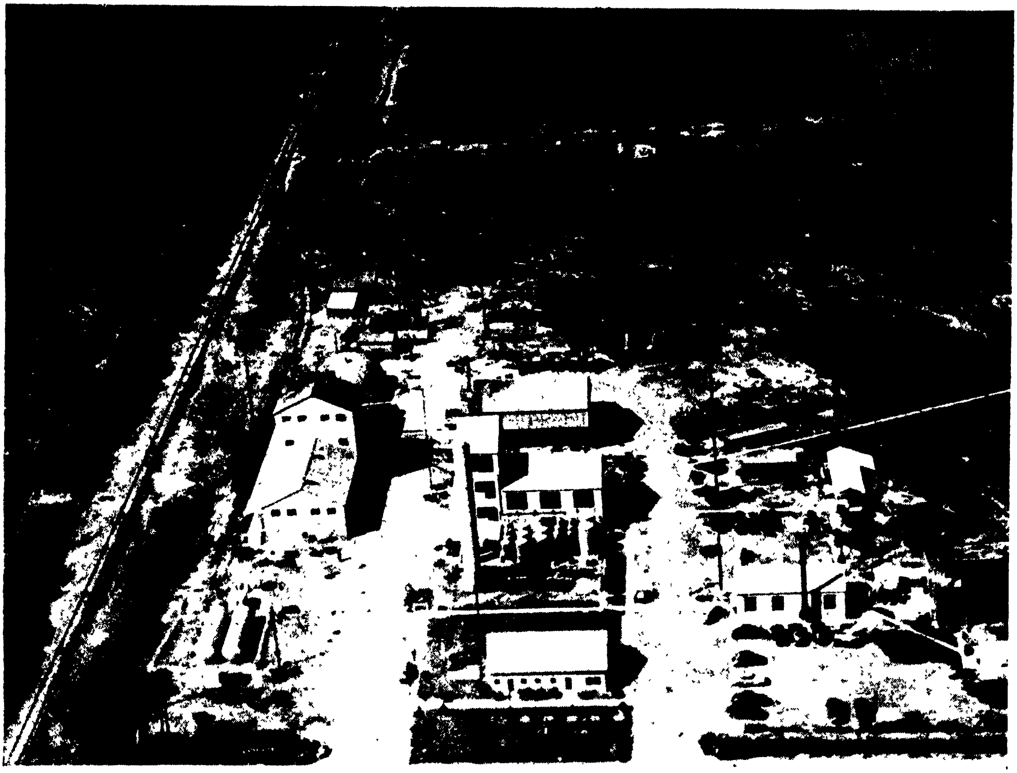
ASH IN ALFALFA MEAL (7)

Percentages and pounds per ton

Leaf meal	11.5%	230 lbs./ton
Standard meal	9.1	180
Stem meal	7.8	159

Composition of ash

Potash (K_2O)	23.5%	54 lbs./ton
Lime (CaO)	40.7	93.6
Soda (Na_2O)	1.7	3.9
Magnesia (MgO)	4.9	11.3
Phosphoric acid (H_3PO_4)	8.5	19.5
Sulfuric acid (H_2SO_4)	5.7	13.1
Silica (SiO_2)	9.5	21.8
Chlorine (Cl_2)	3.0	6.9



sugar beets or other crops planted in rotation (Table 2).

The time between seeding and harvest depends upon climatic conditions and upon the use for which the crop is intended. If it is intended for hay, the crop may be permitted to reach a one-quarter to one-half bloom stage. Alfalfa intended for dehydration is usually cut in the pre-bloom or one-tenth-bloom stage in order to obtain maximum leafiness. This stage may be reached in 45 to 90 days after spring growth starts. The time varies with weather. Repeated cuttings are made at intervals of 35 to 60 days. If planted by the first of April, cuttings are possible in California according to the following program: May 15, June 25, July 30, August 30, October 5. Under favorable climatic circumstances a sixth or seventh harvest may be had during the late fall and winter months.

As with any crop, many factors affect yield. The average annual yield for California is 4.6 tons of hay or meal per acre. Other States report averages in the range of two to four tons per acre. Under ideal growing conditions much higher yields than these averages can be obtained; seven and eight tons are common, and as much as 12 tons per acre per year has been reported. Once a good stand of alfalfa is established in fertile soil, it will maintain itself for a long period of years, provided diseases such as wilt, leaf spot or stem nematodes are not serious, and provided proper cutting practices are followed. It is desirable that alfalfa enter the winter period with a good supply of nutrients in the crown and roots. Crown buds which develop in the fall are largely responsible for the next season's growth. It is advantageous not to cut too late, but to allow sufficient plant growth in the fall to provide reserves of food material in the plant (12).

Utilization

Alfalfa is the most important forage crop grown in the United States. In 1919 about one-eighth of the total hay acreage was in alfalfa; by 1938 alfalfa was grown on 13.5 million acres, amounting to over one-fifth of the entire hay acreage. The average acreage in alfalfa for the period 1942–46 is reported as 15.3 million acres, with an annual production of 34 million tons. Alfalfa is grown for seed on approximately one million acres. The amount of alfalfa meal produced during the 1946–47 season is reported as 700,000 tons. The economic value of alfalfa varies greatly from season to season and from locality to locality. During the past few years prices have been high, but currently there has been some reduction in price, particularly of the lower grades. Statistics of the U. S. Department of Agriculture (26) list $20.20 as the average price received by farmers for alfalfa

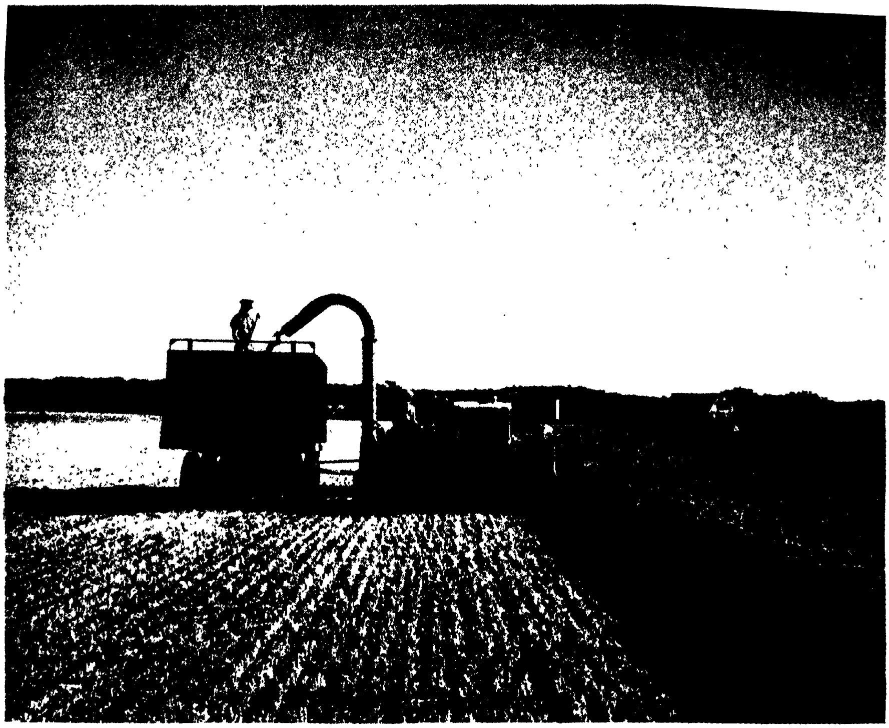
TABLE 2

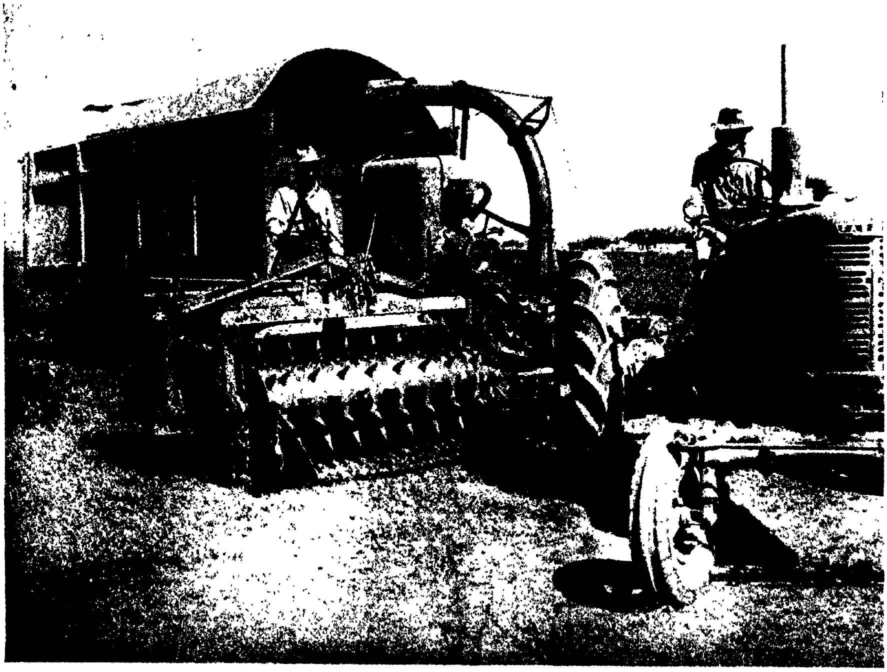
EFFECT OF CROPPING SYSTEMS ON YIELDS (13)

Cropping system	*Yield in bushels per acre, average 1911–1944*	
	Corn	Wheat
Alfalfa, 4 years; corn, wheat, for 12 yrs.	27.7	19.1
Corn, soybeans, wheat	25.0	16.8
Corn, corn, wheat	20.1	14.4
Continuous cropping	16.1	14.7

FIG. 2 *(Upper).* Cabot's Valley Vitamins, Inc., plant in McAllen, Texas, for dehydrating and chemically processing alfalfa. The solvent extraction building for carotene and chlorophyll production is in the center foreground behind the tank yard. *(Courtesy Godfrey L. Cabot, Inc.).*

FIG. 3 *(Lower).* The Koelling-Thompson alfalfa dehydration plant at Topeka, Kan. *(Courtesy U. S. Dept. Agr.).*





hay, loose, during 1946. Grade No. 1 alfalfa hay, baled, sold in Kansas City for an average of $32.52 per ton.

Many variables affect the quality of alfalfa products. The U. S. Department of Agriculture has established standards for alfalfa hay, and the Association of American Feed Control Officials has defined four types of processed alfalfa. Hay standards are based on leafiness, color and foreign material. Leafiness and absence of coarse stems are of major importance as affecting the protein content of the hay. The amount of green color indicates carotene content and reflects the conditions under which hay was produced.

Standards for dehydrated alfalfa have been defined by the trade rules of the American Dehydrators Association, 53 West Jackson Blvd., Chicago 4, Illinois (3). According to their rules, a product may be called dehydrated "provided that the freshly cut alfalfa having a moisture content of not less than 50% has been artificially dried at a temperature of at least 100° C. or 212° F., that the drying process covers a period of not more than forty minutes, and that there be no admixture of sun-cured alfalfa".

The finer-grade hays find their major use for dairy cattle. Coarser hays are used for horses, sheep and feeder cattle. Hay is often ground to produce alfalfa meal and alfalfa stem meal. A sharp distinction should be made between ground hay and dehydrated alfalfa meals, since the latter are of higher carotene and protein content, and usually command $10 to $20 per ton higher price.

Because the composition of alfalfa hay and meal varies greatly, there exists a wide range in nutritional quality and price. Of primary importance as affecting carotene, protein and fiber content is the stage of growth at which harvesting occurs (Table 3).

Losses of nutritive value during hay production are inevitable. One of the largest losses results from destruction of carotene by sunlight, oxidation and enzyme action during the curing of hay. This loss amounts to 80–90 percent of the total carotene content of the alfalfa plant.

Losses due to inclement weather are of concern in hay production. Even a light rain will leach as much as 20 percent of the nutritives from field hay, and continued rains completely destroy the crop. Fog and heavy dews frequently affect the color of hay and may cause mildew and decay, or if damp hay is stacked, destruction caused by overheating due to microbial activity is likely to occur.

TABLE 3

APPROXIMATE PROTEIN AND FIBER CONTENT OF ALFALFA HAY PRODUCED AT DIFFERENT MATURITIES (15, SUMMARIZED FROM CHART)

	Stage of maturity				
	Buds	*1/10 bloom*	*1/3 to 1/2 bloom*	*Full bloom*	*Seeds ripening*
Proteins	19.5	18.0	17.3	16.0	14.5
Fiber	28.0	30.0	32.8	33.0	35.0

Alfalfa seed production is in some degree a specialized enterprise because many areas do not produce good seed. Several cuttings can be made for hay or dehydrated alfalfa; then the plants can be allowed to mature for harvest of seed. The farm value of the 1.6 million

FIG. 4 (*Upper*). Loading cut alfalfa into a truck that will haul it to a nearby dehydration plant. This 160-acre field, on the Walter Thompson farm three miles northwest of Topeka, Kansas, was seeded in 1946. In May, 1947, it produced enough to yield about 1½ tons of dehydrated alfalfa per acre. *(Courtesy U. S. Dept. Agr.).*

FIG. 5 (*Lower*). An alfalfa cutter, chopper and blower. Dixon, Cal. *(Courtesy U. S. Dept. Agr.).*

TABLE 4

APPROXIMATE COMPOSITION OF GREEN ALFALFA, ALFALFA HAY, AND ALFALFA MEALS (28)

Alfalfa	*Moisture*	*Ash*	*Crude protein*	*Ether extract*	*Crude fiber*	*Nitrogen-free extract*	*Calcium*	*Phosphorus*
	%	%	%	%	%	%	%	%
Immature	79.4	2.9	5.2	0.7	3.8	8.0	0.28	0.09
In bloom	77.2	1.8	3.2	0.6	7.8	9.4	0.39	0.07
Hay	7.2	8.0	15.4	1.6	30.3	37.5	1.51	0.21
Leaf meal	8.5	14.4	20.9	2.6	15.7	37.9	1.42	0.25
Meal	8.2	10.0	15.2	2.2	27.5	36.9	1.56	0.22
Stem meal	9.1	7.7	11.4	1.3	36.1	34.4	.....	....

bushels of seed produced in 1946 is quoted as 36.5 million dollars (26).

Dehydrated Alfalfa

The beginning of the alfalfa meal industry occurred in 1903 when Mr. Otto Weiss of Wichita, Kansas, ground alfalfa hay for use in commercial mixed feeds. Later, ground alfalfa was mixed with molasses and used to feed cattle and horses.

As the mixed-feed industry grew, a preference for green alfalfa meal developed. With the newer knowledge gained during the last 20 years about vitamins and related minor components, quality has become increasingly important in the sale of alfalfa products. The first mechanical dehydrators were built about 1930. It has long been recognized that serious losses of valuable nutrients occur during the natural curing of hay. Making hay in many sections is a gamble with the weather, and even when the weather is good, large losses of carotene and other oxidizable nutrients occur, as well as a 10 to 30 percent decrease in protein due to leaf shattering and loss during curing and handling (19). Feeding trials have shown the superior value of dehydrated alfalfa over hay made from the same field (4).

TABLE 5

PRODUCTION AND PRICES OF SUN-CURED AND DEHYDRATED ALFALFA MEAL (18)

Year	*Dehydrated meal, 17% protein*		*Sun-cured meal*	
	Tonnage	*Av. price per ton at Kansas City, Mo.*	*Tonnage*	*Av. price per ton at Kansas City, Mo.*
1943–44	245,000	$55.15	421,000	$39.50
1944–45	377,100	60.30	491,100	43.65
1945–46	497,000	60.40	604,600	44.05
1946–47	566,700	59.30	481,800	43.35
1947–48	707,200	61.65	379,600	43.55

In spite of high cost of equipment necessary for dehydration, the number of dehydrators has increased rapidly, especially in the years following the close of the war. Fortunately, increased recognition of the value of the meal and shortages of other ingredients have maintained price and demand at a high level. Although the production of ground alfalfa hay has remained practically constant, the amount of dehydrated alfalfa has tripled.

Manufacturing Process

Although there are a number of low-temperature tunnel-type driers, most commercial dehydrators use a high-temperature, rotating-drum type which burns either natural gas or fuel oil.

Units are usually located within a five- to ten-mile radius of at least 600 acres of good alfalfa. Operators either raise their own alfalfa or buy from farmers.

In the latter instance the farmer usually produces the alfalfa to a stage suitable for cutting (one-tenth to one-third bloom), and the operator with his harvesting equipment (tractor, mower, chopper, blower, and wagons or trucks) harvests the crop on a price-per-ton-of-meal-produced basis. In California this price is $8 to $9 below the current price for baled hay, for example, $17 to $18 per ton if baled hay is selling at $26 or $27 per ton.

FIG. 6. C. H. Koelling stacks up bags of dehydrated alfalfa at the plant of which he is part owner, the Koelling-Thompson dehydrating plant at Topeka, Kan. *(Courtesy U. S. Dept. Agr.)*.

Field chopping of alfalfa in pieces 1½ to 3 inches in length at the time it is mowed makes possible automatic or nearly automatic handling throughout the rest of the process. In the most modern installations the wagons dump their loads on conveyor belts which feed the wet material into the inlet of the drier at a constant regulated rate. The drying capacity of the rotating drum drier is usually about one ton of meal per hour. The chopped alfalfa drops into a blast of hot air and gas, which is maintained at 1,500° to 1,700° F. As the alfalfa travels through the inner drum of the drier, almost instant evaporation of a large portion of the moisture (78–82 percent of the weight of the herbage) occurs with a corresponding drop in temperature of the heating medium to about 250° F. at the exit end. After two more passes through the drier, the chopped dried alfalfa is moved by a large fan through a cyclone which drops out large incompletely dried stems and woody fragments. The rest of the material goes through a hammer mill where it is ground to 40- or 60-mesh average size and then to collecting bins for sacking.

In this type of operation, leaves dry in 30–90 seconds and are blown through the machine with that rapidity, while stems and heavy pieces require four to six minutes. A system of controls is used which automatically cuts down on the fuel if too little alfalfa is fed into the machine or if for some other reason the exhaust temperature rises. The amount of heat required to evaporate the moisture from the alfalfa as it is fed to the machine requires accurate control. During continuous operation the amount of fuel remains constant and the rate of feed of green alfalfa is varied to balance the heat input.

One and sometimes two men are required to feed the green alfalfa into the dryer, watch the gauges and guard against stoppages. Another man handles bagging of the meal. Where alfalfa leaf meal is produced, the meal as it comes from the hammer mill goes through automatic sifters. Because leaves produce a finer powder than the more fibrous stems, leaf meal goes through the screens and is sacked separately. The coarser particles remain on the screens and are sold as stem meal. The proportion of leaf meal to stem meal depends upon stage of maturity at harvest and type of grind and setting of the mill and screens.

Frequent chemical analyses are needed to insure control of protein and fiber content in the finished meals. The installation and operation of a complete alfalfa meal and dehydration plant is a business of considerable magnitude, requiring between $100,000 and $200,000 in capital and demanding a combination of business, mechanical and farming skills. The overall cost of production after the alfalfa is purchased from a farmer may vary from $15 to $23 per ton, depending upon length of season, investment, labor and operating costs, and especially fuel prices. During periods of low prices, freight rates to centers of distribution may be an important factor in the success or failure of operation.

The price of alfalfa meal is largely determined by the percentage of protein, although to an increasing extent the feed trade is demanding a guaranteed carotene content for the better meals. According to the grade of alfalfa, labels on each sack commonly guarantee the minimum percentage of protein and maximum percentage of fiber, and perhaps ash and fat content.

Uses in Animal Feeding

Although only about three percent of the total tonnage of alfalfa is now converted into meal, it is the writer's opinion that this proportion will continue to increase as a result of advancing nutritional knowledge relative to the proper use of alfalfa in mixed feeds and also as a result of technical improvements which will serve to increase and stabilize nutrients such as carotene (provitamin A), riboflavin, thiamin, pantothenic acid and choline. Alfalfa meal supplies about one and a half times as much protein as most grains and about half the nitrogen-free extract (carbohydrate) which grains contain. The protein provides such essential amino acids as arginine, threonine, lysine and tryptophan but is somewhat low in cystine and methionine. Dehydrated meal is particularly rich in dietary factors supplied by green forage or good green pasture and is therefore widely used to supplement poor hay and increase feed utilization during the winter or when green feeds are not available.

Three to five percent of good dehydrated alfalfa is recommended in poultry feeds. This amount will supply nearly all of the vitamins A and E needed and about half the requirement of riboflavin as well as considerable quantities of choline, thiamin, folic acid and "grass juice factors". Numerous investigators have reported improved hatchability, lowered mortality, rapid growth, better feed conversion and increased egg production occasioned by the use of mixed feeds containing adequate but not excessive amounts of alfalfa. For turkeys a somewhat higher level of meal, 5–10 percent, is advocated. For further discussion of the use of alfalfa for poultry the reader should consult Handbook of Poultry Nutrition by W. Ray Ewing (10).

TABLE 6

COMPOSITION AND APPROXIMATE CONTENT OF MINOR CONSTITUENTS OF FRESH ALFALFA MEALS (19)

	Leaf meal	*Standard meal*
Crude protein	22.7%	15.7%
Nitrogen-free extract	39.2	37.9
Crude fiber	16.3	26.8
Crude fat	2.8	2.0
Ash	11.5	9.2
Moisture	7.4	8.4

Minor constituents (leaf meal) ppm.

Chlorophyll	3000
Xanthophyll	425
Carotene	300
Phytol	1000
Vitamin E	250
Vitamin C	4000–9000*
Riboflavin	120
Folic acid	12
Choline	900
Panthothenic acid	40
Vitamin K	80–100
Niacin	50
Thiamin	7

* Vitamin C is retained only under special condition of dehydration and storage.

In swine feeding, dehydrated alfalfa meal has shown particular value in increasing breeding efficiency, improving lactation, and increasing the average number of pigs weaned per litter. The use of 10 to 15 percent or more in the ration is recommended by Professor Damon Catron of Iowa State College (8).

Chopped (not ground) dehydrated alfalfa as well as sun-cured hay finds its most extensive use in cattle feeding. The manufacture of pellets of meal with about 10 to 15 percent of molasses added increases palatability by eliminating the qualities of a light meal that are objectionable to cattle.

In spite of its advantages, alfalfa is by no means perfect. Disadvantages when fed in excessive amounts to poultry include lack of palatability, high fiber content and a tendency to decrease rate of growth of chicks and broilers. Whether these difficulties can be overcome by the wet-processing method of making a high-protein concentrate, with elimination of fiber components, is not yet known.

Other Uses

The writer believes that the industrial utilization of alfalfa is today in an infant stage which compares with the development of the corn and soybean industries 30 years ago. Alfalfa is more difficult to process than the grains, but the advantages of an industry based on a plant which takes nitrogen from the air and produces more protein per acre than almost any other crop are obvious.

Vitamin C and other water-soluble vitamins could be recovered from alfalfa juice. Several companies are using or have used alfalfa meal as a source of carotene (provitamin A), chlorophyll and xanthophyll. The process in barest detail involves the solvent extraction of high-quality leaf meal with hexane or other solvent, concentration of the solvent, and separation of the chlorophyll and carotene by chemical processes. The carotene concentrate has found use as a replacement for vitamin A in feeds. Chlorophyll is used in pharmaceutical and air-purification products (14). With adequate research, no doubt economical methods of obtaining phytol, choline, vitamin K and other compounds listed in Table 6 could be developed.

The use of alfalfa in human nutrition has been suggested and tried, perhaps first by Nebuchadnezzar when he got down on his knees and ate "grass", for his was the area in which alfalfa may have originated as a forage plant. More recently Brown and Tisdall (6) reported the use of two percent of alfalfa meal in special cereal mixtures for undernourished children because of its high vitamin A content. Fox and Wilson (11) have published a bulletin, "Lucerne as a Food for Human Consumption", in which they point out that the leaves of alfalfa contain five times as much vitamin C as oranges, grapefruit or any of the common leafy vegetables. They also discuss the value of the protein, minerals and vitamin A of this plant for human food. They suggest using alfalfa leaves in green salad and omelettes, in cooked form like spinach, or in tea. They report the use of alfalfa as a vegetable in China and parts of central Russia. In this country dried alfalfa leaves mixed with mint are packaged and sold in most health food stores. It is possible that a variety of alfalfa could be developed which would be sufficiently tender and bland in taste to win acceptance as a vegetable.

The "wet processing" methods of fractionating green alfalfa offer promise for new alfalfa products. Nebraska Chemurgy Project Bulletin No.6 (25) reports experiments on grinding green alfalfa through an expeller press which separates the juice containing the plant pigments and most of the protein from the fibrous material. The dried juice contained 40 percent of protein and retained about 90 percent of the carotene found in the plant. Bickoff, Bevenue and Williams (5) have reported a similar process, using a Rietz disintegrator and pressing to recover a pigment-rich juice. A firm in Los Angeles manufactures an alfalfa powder made by spray-drying alfalfa juice pressed from green alfalfa. Chibnall (9) has reported on methods of concentrating the chloroplast pigments contained in the plant juice by centrifuging. They can also be concentrated by heating the juice until coagulation of the protein occurs, as described in the Nebraska report (25) and by Bickoff *et al.* (5). Paper has been manufactured from alfalfa fiber.

Research Problems Related to Industrial Utilization

There are many problems to be solved in handling alfalfa. Some of them concern the feed trade and the consumer to an extent little realized by those outside the feed industry. Both carotene from alfalfa and vitamin A from marine sources are destroyed in feeds by a few months' storage at summer temperatures. Clarence Johnson of Ralston-Purina Company (1) has estimated that the economic value of carotene lost between the time alfalfa is cut and when it is fed amounts to 13.5 million dollars annually.

Stabilization by means of packaging in inert gas has been investigated (16, 29). Other investigators (20) have shown that low temperatures (32° F.) and vacuum packaging were both very effective in reducing carotene losses. Aside from cold storage, industrial methods for preventing losses have not been developed. It has been suggested that packaging in modern multiwall paper bags with nitrogen or carbon dioxide would prevent some of this loss.

Industrial processes for eliminating fiber content and increasing palatability still await development. The chemical fractionation of alfalfa is an infant industry deserving of attention. Much clinical work could be done on alfalfa components such as chlorophyll and water-soluble vitamins. Almost unlimited nutritional work can be undertaken to supplement the little now known about feeding alfalfa and to determine the value of various alfalfa fractions.

It is encouraging to note that the American Dehydrators Association has formed an Alfalfa Research Council and expects to encourage and finance research on problems related to the industry.

The Western Regional Research Laboratory of the U. S. Department of Agriculture is working on the physical and chemical fractionation of alfalfa and the characterization of the various fractions. A number of State Experiment Stations, particularly in States having large dairy industries, and private firms and individuals are also engaged in research on alfalfa. With this impetus many interesting developments and continued growth of present enterprises can be expected during the coming years.

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Microbial Farming

Does the production of proteinaceous food by extensive cultivation of baker's yeast in England and Germany during the recent war presage an eventual source of supplementary food for the world through the utilization of microorganisms?

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Introduction

RAPID advances in the science of nutrition during recent years have led to a critical reexamination of our present system of agriculture. Farm products are no longer estimated solely in bushels or tons per acre but are evaluated in terms of the quantities and qualities of the essential nutrients they contain. Today agriculture is thus planned according to man's dietary needs.

Basically agriculture is a process of transforming the materials of the soil and air into various forms of food and other products with sunlight as the primary source of energy. How efficient the agricultural practices are depends, therefore, on how much energy they can fix or transform, and on how much inorganic material they can render into forms available for human use. From this point of view a critical review of our present agricultural situation can be made, and, what is more important, a number of interesting prospects can be discerned on the broadened horizon. Among these prospects the possibility of using microorganisms as major crops appears to be most interesting and fundamental.

Although the use of microorganisms in the production of food is an art as old as history itself, until very recently it played only a secondary or minor role. Microbes were primarily used, unwittingly at first, to improve the taste and the digestibility of the food, as in the cheeses of Europe, soybean products of Asia, 'poi' of the Pacific islands, and the native beer of Africa. Later they were used to supply certain essential nutritive factors, for example, vitamin B in the form of yeast tablets and yeast extracts. Only during the two world wars, however, was serious attention given to the possibility of using microorganisms to furnish the more bulky, body-building and energy-producing articles of food, such as proteins and fats. Experiments have shown that in many cases these food materials can be produced satisfactorily in respect to both quantity and quality, by means of microorganisms. Furthermore these organisms can do the job more efficiently and quickly than the higher plants and animals that we now employ. The culture of them requires comparatively less labor and very much less space. They can be grown in factories instead of fields. Consequently they are less dependent upon the natural and climatic conditions and are more compliant to human control. Considering these obvious advantages, it is reasonable to imagine that some day in the future "microbial farming" will form an integral part of, if not wholly replace, our present system of agriculture. In view of the bitter experiences during two world wars and the famine situation of the post-war period, a quick and efficient way of mass production of food in a concentrated form will certainly engage serious attention. Industrial concerns, ever eager to expand their activities, will find in it a long-sought opportunity to enter the field of farming because it promises an immediate turnover and is well adaptable to their technical facilities.

Of course, agriculture supplies us not only food but also other materials. Fibers, resins, latex, dyes and drugs are the notable examples. But all these nonfood products are rapidly being replaced by the synthetic substances of modern chemistry. Perhaps food products, too, will some day be synthesized; indeed, some have already been patented. However, as far as we can see, the day is still far off. And before that time we shall have to be content with the living organisms for our food supply. Among the living organisms, as we have shown, the microorganisms appear to answer our requirements and to fit into our industries best of all.

The principal classes of food are the proteins, fats, carbohydrates, vitamins and minerals. All these substances are known to exist in some forms of microorganisms. A complete diet, satisfactory at least theoretically, can be obtained exclusively from a mixture of these organisms. Of course, many problems will have to be solved before such a major change can be realized. The choice of organisms, the process of production, the nutritive values and the palatability of the products remain to be investigated in greater detail. Parts of these questions have already been answered, as shown in the following examples. In the rest, it will be seen that a microbial crop is already established in commercial production; in the second, that one is still in the laboratory stage; and in the third, that the organism is still to be selected and domesticated, for thus far it has not been considered as a potential source of food.

Proteins

Let us begin our discussion with the microbial production of proteins, the most important and often a limiting factor in our food supplies. As early as the first world war the Germans were known to have developed a strain of yeast for the production of protein. The yeast was produced on a commercial scale to supplement the deficient diet during the blockade. The first experiment was not very successful, owing perhaps to improper administering of diet composition. In the second world war considerable progress was made, and thousands of tons of protein yeast were produced and used with satisfactory results. In the allied countries similar investigations were carried out, and commercial processing technics were developed. Since the food situation was then less urgent the experiment did not get much beyond the pilot plant stage and no large scale production measures were attempted until near the end of the war.

The organism developed in the British laboratories is a strain of baker's yeast, *Torulopsis utilis*. When dried in the form of flakes it is cream white in color, has a meat-like taste and is very rich in protein and the B-vitamins. As shown on the following page, weight for weight it contains about twice as much protein as fresh beef or dried whole milk and about the same as soybean. It has all the essential amino acids in good balance, and is especially rich in lysine which is usually deficient in the proteins of plant origin. Food yeast lacks vitamin A but is very high in the B complex; in fact, yeasts in general have long been used as a source of these vitamins. Feeding experiments have shown that pigs thrive well on a diet entirely of maize supplemented with 5% to 20% of food yeast. Nutritive trials on school children have indicated that inclusion of yeast in their biscuits and milk leads to a greater increase in body weight.

Torulopsis yeast grows very rapidly. It has a generation time of two to four hours, or a tenfold increase in ten hours. It can be cultured in a continuous manner, and once inoculated the cultures can be kept going with periodical additions of nutrients and withdrawing of the suspension of yeast cells. Sugar or molasses can be used as the carbohydrate source, and nitrogen and phosphorus are supplied as ammonium sulphate and superphosphate. The conversion of inorganic nitrogen to protein is almost quantitative, or 100% theoretical. More than half of the carbohydrate supplied is converted into protein, and most of the remainder into the other cell substances. The maximum overall efficiency as a converter of food energy is many times that of vertebrates. Thus, whereas the pig, the most efficient food producer among farm animals, retains 20% to 40% of the calories taken in as feed in the increase of body weight (0.036–0.073 gram of solid per calorie), and only a part of it is edible, yeast shows an efficiency of 50% or even 60% and yields 0.125–0.25 gram of solid corresponding to 0.6–1.1 calories per calorie intake. The efficiency of the production of vitamin B is even more striking, being 10 to 200 times that of any animal product per calorie of feed.

COMPOSITION OF FOOD YEAST, *Torulopsis utilis*, COMPARED WITH THAT OF SOME OTHER FOODS

	Water %	Protein %	Fat %	Available % Carbohydrate	Calories per 100 gr.	Calcium mg. per 100 gr.	Fe	Vitamin A	Vitamin B	Riboflavin	Nicoti acid
							mg/100g	IU/100g	mg/100g	mg/100g	mg/10
Food yeast	8.	43.1	2.4	3.0	206	127	20.0	0	2.0	5.0	40–4
Dried milk	4.	25.6	26.7	35.6	485	895	0.8	1.070	0.3	1.15	24
Beef	69	19.0	10.0	0	166	10	4.0	50	0.08	0.25	43
Dried peas	7.	24.5	0	50.0	298	61	4.7	200	0.45	0.30	18
Soybean	8.	40.0	18.0	12.6		210	7.4	16–350			

From "Food Yeast, a Venture in Practical Nutrition," 1941, and "Soybean" Cornell 1945.

A commercial factory for producing food yeast has been projected by the British Colonial Office in Jamaica in cooperation with the West Indies Sugar Co., Ltd. The factory proper will have a ground space of about 20,000 square feet and cost £110,000 to build. The total personnel and labor will be about one hundred, and with a little addition will be able to handle expansion of the factory to twice its present size. The factory will produce 12 tons of dried yeast in 24 hours. Using molasses as raw material the cost of producing dried food yeast will be about sixpence (ten cents) per pound.

Similar commercial plants for food yeast have existed for sometime in Germany, and others have been recently established in America, Sweden and elsewhere. Such factories constitute an ideal means of improving the dietary of people depending chiefly on cereals, and are especially suitable for countries having a low standard of living.

Yeast is by far the cheapest method of producing protein from carbohydrates and nitrogen. To produce the same amount of protein as a yeast factory of the above mentioned size would require a hundred thousand head of cattle. Besides, far more space and labor would be needed. Animals can synthesize proteins only indirectly. Inorganic nitrogen supplied to the soil has to be first transformed by plants in order to be of use to them. Both transformations are quite inefficient, and the process entails a double loss of material. Even land supporting leguminous plants, which yield proteins directly available as human food, is much less efficient acre for acre than land made to yield sugar for the growing of yeast. Furthermore, as substitute for sugar, nearly any carbohydrate properly treated can be used by yeast. Hydrolyzed sawdust, pulping waste and many kinds of inedible carbohydrates have been tried with success. Since all plants produce carbohydrate in one form or another, the variety of raw material is practically unlimited. Yeast requires no products of organic origin besides carbohydrate. Phosphate is obtained in the earth's deposits, and an inexhaustible nitrogen supply can be derived by artificial fixation from the atmosphere.

Fat

Another important constituent of food is fat which supplies energy in a concentrated form and often contains vitamins A and D as well as other growth factors. One gram of fat gives upon oxidation in the body, nine calories of energy, *i.e.*, about twice as much as that given by the same amount of carbohydrate or of protein (4 cal./gm.). It is digested more slowly, stays longer in the body, and for these reasons is generally used in cold climates and in emergency field rations where bulk and weight are important considerations.

The fact that microorganisms can synthesize fat like the higher plants and animals had been long known but had not been industrially investigated until the first world war. Because of the shortage of fat the Germans were compelled to produce yeast fat on an industrial scale. The organism used by them was *Endomyces vernalis* which under favorable conditions can produce fat equivalent to 20% to 25% of its dry body weight. A great deal of research was done on the problem in the Institüt für Gärungsgewerbe in Berlin. The optimal conditions for growth appear to be 15° to 20° C temperature, good aeration and a medium rich in sugar and nitrogen. But to obtain high content of fat the nitrogen supply must be reduced to a minimum. Fat accumulation is also favored by the presence of alcoholic vapor in the air. The production of fat by the organism apparently consists of two phases. First the organism is allowed to multiply rapidly to give large quantities of cells; then the cells are "fattened" in a medium of low nitrogen. Several industrial processes have been developed on this basis. For good aeration the organism is generally grown on surface cultures. The yield obtained is usually about 10 grams of fat per 100 grams of sugar consumed, although in some cases 30% conversion has been reported. Instead of sugar, molasses, sawdust, hydrolyzed wood and other cellulosic wastes can be used. The fat so obtained is recovered either by extraction or by autolysis. It keeps well in the absence of air.

Yeast fat contains palmitic, oleic, linoleic, lauric and other fatty acids as well as phospholipids, lecithins and sterols. No feeding experiments have been published using the yeast product as a sole source of fat, but judging from its composition, yeast fat probably does not differ much nutritionally from other fats of plants and animals.

There are many other fungi which accumulate fat in their mycelia, for instance, *Penicillium*, *Aspergillus*, *Fusarium* and *Oospora*. Among these, *Penicillium javanicum* van Beyma can yield as much as 40% fat of its dry weight. Semi-large scale apparatus for its production has been worked out and tried with success. Recently a new strain of yeast, *Rhodotorula gracilis,* has been developed by scientists in Sweden. Its fat yield is even higher, over 60%. The analysis of this yeast and that of the protein yeast are as follows:

COMPARISON OF PROTEIN YEAST (*Torulopsis utilis*) AND FAT YEAST (*Rhodotorula gracilis*)

(From Enebo, Anderson and Lindin, 1946)

	T. utilis %	*Rh. gracilis* %
Protein	59	13
Fat	3	60
Carbohydrate	30	24
Mineral substances	8	3

The essential conditions for fat accumulation are, again, a low nitrogen and phosphate supply. There is a reciprocal relation between fat content and protein content. With plentiful nitrogen and phosphate salts the organism grows rapidly (one generation in about three hours) and accumulates a large amount of protein but has very little fat. When the mineral supply is decreased, the growth rate decreases to one generation in eight to nine hours with an increase in fat content to 20%. When the mineral supply is at the lowest, growth is slowed down to one generation in 15 to 20 hours, while the fat content runs up to 60% of its dry weight.

Because of the slowness of the process of fat formation, continuous production, as with protein yeast, is not industrially feasible. Two methods of commercial production are suggested. One is to grow the yeast continuously with plentiful minerals to obtain a rich big harvest of cells with comparatively low individual fat content. These cells can be used for both their fat (15% to 30%) and protein (15% to 35%). The alternative method is to culture the yeast in batches in a low mineral medium to obtain a high percentage of fat in the comparatively smaller number of cells. A process combining the merits of both has been tried out satisfactorily in Sweden. The yeast is first cultured continuously in a mineral-rich medium, and portions are taken out periodically to be fattened in batches. Industrial production of fat yeast from hydrolyzed wood was known to have been planned in Germany in 1944. Details of the species and conditions of culture are not available. Judging from the war situation at and immediately after that time, full scale operation was probably never realized.

The efficiency of fat production by *Rh. gracilis* has not been surpassed either in microorganisms or in higher forms. For 100 grams of sugar intake a yield of nearly 18 grams of fat can be expected. And the rest can largely be accounted for in the proteins and carbohydrates of the cells. Assuming that two grams of sugar are needed to produce every gram of cell protein and carbohydrate, it is estimated that about 4.5 grams of sugar are used to form one gram of fat, or an energy efficiency of about 50%. It is difficult to compare this figure with that of higher plants or animals. As shown in the above section, their energy efficiencies in general are always low. Common experience also indicates that the fattening of animals is a very wasteful process. Whatever the case, we must remember another important point, that no animal or higher plant can accumulate as much fat as would amount to 60% of the total dry weight of the body as a whole.

In spite of its efficiency as a fat producer, yeast has so far not been produced commercially with profit except under particular conditions, as in the war. But with improvement in strain and technique there is no good reason to exclude microorganism from competing with higher plants and animals as fat sources, even in times of peace.

It may be added here that all yeasts are rich in ergosterol which upon irradiation acts as vitamin D. In fact, commercial vitamin D is derived mostly from this source. The colored species of yeast contain also pigments of carotene, which are closely related to vitamin A. Recently it has been reported that *Rhodotorula gracilis* shows a vitamin A activity of five to ten International units per gram of dry weight, a figure comparable with that of dried whole milk. Lastly it must be remarked that yeast fat contains linoleic acid which has been shown to be necessary for growth but is not synthesized by animals.

Carbohydrates

It remains for us now to consider the last major class of food, carbohydrates. This group supplies both the energy for growth and the raw material for syntheses of all the other forms of food. In the above examples, be it the production of protein or of fat, the basic material is always a carbohydrate. It is true that our world is fairly well stocked with carbohydrates of the higher plants, and there is no immediate danger of shortage. Nevertheless there are places where the supply of this important material is too limited. As it is, agriculture still cannot operate in many parts of the earth and is not always dependable at all times. The space required by farming and the bulk of its products further restrict the transportability and availability of agricultural produce. A consideration of the production of carbohydrates by microorganisms is, therefore, of more than theoretical interest.

Of course, all microorganisms produce carbohydrate, but most of them are essentially converters rather than primary synthesizers; they transform one carbohydrate into another. Here we shall consider only the autotrophic forms which make carbohydrates from carbon dioxide and water. The energy for this synthesis may come from sunlight or from oxidation of inorganic substances. All algae and some bacteria belong to this category. So far none of these organisms has been investigated or cultivated with a view to developing them into a carbohydrate crop.

The one organism that has been subjected to somewhat extensive cultivation is *Chlorella vulgaris*. It is a unicellular green alga widely used by physiologists in researches on metabolism. Its composition is approximately as follows:

The carbohydrate fraction consists of polysaccharides hydrolyzable by 3% acid. It includes approximately 70% of "hemicelluloses," 28%–30% starch, 4%–5% disaccharides and 4%–6% hexoses.

The organism requires no organic material for growth. Being photosynthetic it manufactures its own food out of carbon dioxide with the energy of light. It is usually cultured in a dilute solution of inorganic salts such as $MgSO_4$, KNO_3, KH_2PO_4 and a trace of ion. The cultures are illuminated either with indirect sunlight or with incandescent lamps. A stream of air containing 5% carbon dioxide is bubbled through the medium to supply raw material and agitation.

In such cultures the organism grows first rapidly and then more slowly until a saturation point is reached. During the period of exponential growth the population can under suitable conditions increase two hundred fold in four days, corresponding roughly to a generation time of 11 to 13 hours. This is by no means its maximum biological potential, and as yet no attempt has ever been made to attain its highest productivity. With improved methods a higher rate can certainly be secured.

From the above figures we can calculate the approximate productivity of our algal crop and compare it with that of the higher plants. Imagine an acre of land being flooded with water plus the necessary salts to a depth of one meter and then inoculated with *Chlorella.* In about eight days we can get a population density of 2×10^{10} cells per liter, corresponding to about one gram of dry matter. An acre would give us some 4,000 kg or four tons of dry substance of which more than half would be carbohydrate. If the acre of land were planted to corn, one to one and a half tons of dry matter could at best be obtained in a growing season of 90 days. Thus our alga would be 25 to 30 times as productive as corn. This is not surprising when we consider the fact that the entire body of the alga is photosynthetic, while a large part of the higher plant is essentially parasitic and consumes rather than produces carbohydrates.

Our imagined farm is of course purely hypothetical. There are a number of difficulties to be solved before such a practice could be approached. Light is perhaps not a limiting factor. The organism grows well under an illumination of 4,000 lux which is about one twentieth of full sunlight on a clear summer day. At the depth of 5 to 20 meters of sea water, 5 to 10% of sunlight still penetrates and is more than enough for the algae. Nor is contamination by bacteria a very serious problem if purely inorganic salts are used and the organism can be harvested in a rather short time. Temperature and aeration are important factors. Heating device and air supply must be installed. The growth rate of the organism is yet too slow. It is at best comparable with that of the fat yeast and about one quarter that of the protein yeast. Ordinarily the organism declines to increase when the population density reaches 20 million cells per milliliter or about 1/100 the density of the food yeast. This phenomenon of saturation is caused by a substance produced during growth and is inhibitory to both *Chlorella* and a number of bacteria. It may be removed by certain absorbents, and upon such removal the alga can attain up to three times its saturation density. Even then the volume of the cultures to be handled is too large to be practical.

So far there are no data available on the nutritive value of this alga. Judging from its chemical composition we may be fairly sure that it does not differ much from the higher plants which we use as animal fodder. In nature the alga forms a part of the plankton flora and is a primary source of food for fishes; so indirectly it is, *ab initio,* a food for man.

This fact leads us to the consideration of using the sea and fresh water resources of organic materials for human needs. Many discussions have appeared on the subject, and more than once cultivation of these resources has been suggested. Over 70% of the surface of the earth is covered with water, and in it myriad forms of life abound. The sea contains all minerals required for life and compares favorably with good garden soil in fertility. The temperature is even. There is no danger of drought. Plants can be grown down to a hundred meters or more where sunlight still penetrates. Acre for acre it is more productive than land. It has been estimated that in nature a half of the total photosynthetic fixation of carbon dioxide into organic matter is brought about by the plankton of the sea. There, indeed, is a rich supply, too attractive to be long neglected. As far as these resources are concerned we are still in the primitive, hunting and picking stage, although in some waters the Japanese have tried the cultivation of certain seaweeds, and recently the British have been experimentally fertilizing the sea with minerals to encourage the growth of plankton. These ventures may eventually develop into a new system of aquiculture.

As we have stated above, green algae are by no means the only autotrophic organisms capable of synthesizing carbohydrates. There are many forms of bacteria which reduce carbon dioxide with the energy of sunlight or of oxidation of inorganic compounds. Species of purple sulphur bacteria, for example, can use carbon dioxide and hydrogen sulphide and grow at an enormous rate in light with the accumulation of a great deal of organic matter. Even among the algae themselves there are endless varieties to choose from. With proper selection and breeding there is little doubt that a strain can be evolved to answer the requirements of commercial production.

Many polysaccharides are formed by algae, and some are used commercially in large quantities. Paper has been made from algal cellulose, and agar agar is exclusively derived from algae. Recently alginic acid and a number of phyco-colloids have been found useful in the plastic and coating industries and in food manufacture. Algal carbohydrates may not be all edible, but their possible uses in industry and possibly as raw material for the production of foodstuffs, microbiologically or otherwise, should not be disregarded.

All green plants contain vitamin C in their plastids. Algae are no exception. With suitable methods of extraction they may be utilized as a source of the vitamin in addition to being a supply of carbohydrates.

Discussion

Not so long ago microbes in general were looked upon as fearful enemies of man. Livestock and crops as well as human lives were at the mercy of pestilence and plagues. Microbes have caused more losses than the sum total of all the wars and battles ever fought. Only near the close of the last century was it realized that there are microbes of benefit to man. With increasing knowledge of microbial physiology man not only has gradually brought the harmful ones more or less under control but also has domesticated the beneficial ones and harnessed them to his advantage. They are used to fertilize his fields, prepare his food, manufacture a number of useful chemicals and vitamins and even to make drugs to fight other microbes.

Within the last few years, moreover, it has become increasingly evident that probably all organic material in higher plants and animals can be obtained from microorganisms. From what we have discussed it is seen that from the microbes all the important constituents of food can be successfully derived in respect to both quantity and quality. In addition the microbes offer several more advantages. Firstly they are more efficient in converting material and energy than are higher organisms. Less space and labor and raw material are required to produce the same amount of yield. Secondly they grow fast and give a quicker turnover. Thirdly they thrive easily in an artificial environment, less dependent on natural elements and more amenable to human control. They can be reared in any climate, and there is little danger of natural famine. Modern industrial technology and management can be used with little modification in rearing them. The large-scale production methods that have so successfully revolutionized our industries may profoundly alter our food situation, once they are adapted to the field of agriculture. A major change like this, if effected, will certainly permeate into every phase of human activity and bring about social and cultural readjustments that we can at present hardly surmise.

Of course, we are still very far from

any realization of this condition. The practice of microbial farming is still in its infancy; nay, in the prenatal stage. There are many problems to be solved before it can occupy any significant place in our present system of agriculture. The technical problems are perhaps the least difficult. There are innumerable varieties of microbes awaiting our selection and breeding and a vast store of industrial and scientific experience to draw upon. Questions of food habits and of social adjustment are more difficult to meet, but even these are not insurmountable.

Agriculture has a long past and so far has undergone little change. When man first appeared, the earth was already well stocked with higher plants and animals. Naturally it was these higher forms which he hunted and collected and later domesticated. Nearly all of our important crops and our cultivation methods have a long history, so long that their origins are more or less obscure. Although we have made many improvements and discoveries, especially in recent years, we are yet not very much better off than our ancestors in the face of drought, flood and other of Nature's whims, and have not rid the world of the spector of starvation. Agriculture is still restricted geographically and at the mercy of the natural elements. No radical progress such as we have witnessed in industry has ever been approached in it. A large part of these drawbacks is traceable to the intrinsic nature of the plants and animals we have chosen to employ. Of over a million species of living organisms known to science, not more than a few hundred are utilized for intensive cultivation. With our modern knowledge of the activities of so many more organisms there is little excuse for us to stick to the few old forms for our sole subsistence.

One of the primary aims of science and technology is to enable man to be less dependent upon nature. Some vital transformations have already been duplicated in the laboratory, and a few patents have been issued on microbial synthesis of foodstuffs. But we are a long way yet from our goal. Before that goal can be approached the use of microorganisms must receive extensive investigation. Quite a few physiological processes of the higher organisms have been studied via microorganisms to a successful physio-chemical interpretation. Carbohydrate metabolism and respiration are good examples. The study of photosynthesis is already on the microbial level and is gradually on the way to a biochemical stage. And between the present practice of agriculture and the ultimate chemical synthesis the gap may well be bridged by a period of microbial farming.

Utilization Abstract

Hardwood Pulp. Hardwoods, heretofore, have been of only secondary importance in the production of paper pulp and have been used only as filler in the manufacture of high-grade printing paper. In 1946 wood from such trees as maple, beech, birch and poplar accounted for only 16% of pulp consumption and inventory. This secondary position is accounted for by the short fibers of hardwoods, as compared with those of coniferous trees, but government scientists in the National Bureau of Standards have announced possible 75% increase in the use of short-fibered woods for pulp by addition of the synthetic resin, melamine formaldehyde. (*Anon., Pulp & Paper Bull. 6*(*5*): *1. 1948*).

Watermelon Breeding

The application of breeding technique to improving watermelons has been directed toward obtaining disease-resistant varieties and not toward improving other qualities.

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Introduction

OVER 50 percent of the watermelon acreage of the United States is located in three States—Georgia (27 percent), Texas (16 percent), Florida (15 percent)—with the remainder scattered in North and South Carolina, Missouri, Virginia, Iowa, Mississippi, Tennessee, Oklahoma, Arizona and California. Other States grow less than one percent (36).

Although all varieties of watermelons are generally considered to belong to *Citrullus vulgaris* Schrad., great variation occurs within this species, ranging from small, hard, bitter and inedible fruits to the large, succulent, sweet fruits that make watermelons one of the first ten commercial truck crops in this country. There is no adequate classification or cataloguing of the many types and varieties within the species, and such classifications as we do have are so broad as to be almost worthless.

What do we want in a watermelon? In the past we have classified melons on their ability to withstand long distance shipping, on their quality, on their shape, sometimes on their size. These are outward characters, and without consideration of many other factors we are likely to have a melon that can be shipped but that is low in quality, or we can have high quality associated with too low a plant vigor to be produced economically. It is because we have based our evaluations of varieties on too few characters, usually of the fruit itself, and from too restricted a viewpoint, that the history of the watermelon industry, since large shipments to northern markets began in the 1890's, has been a jumble of varietal names. Most of the varieties of 40 to 50 years ago have disappeared, such as McIver, Phinney's Early, Kolb Gem, Duke Jones, Ruby Gem, Green and Gold, Mountain Sprout, Mammoth Ironclad, Ruby Gold, Sugarloaf and Cole's Early. A few, like Florida Favorite, Rattlesnake and Irish Grey, still can be found in seed catalogues but are of minor importance. The Kleckley Sweet, introduced in 1887, and the Tom Watson (1906) are two varieties that are listed in seed catalogues selling seed in the South, but their popularity is on the wane. Any variety, new or old, that is to maintain its position must possess a satisfactory blend of the many factors that go to make a fine variety. Unless vigorous precautions are taken, a variety can deteriorate under ordinary conditions of propagation, and it is likely that a number of varieties that have disappeared have deteriorated. To prevent this, improved methods of maintaining stocks, and seed certification may help. However, there seems to be no established types for the run-of-the-mill variety, and ordinary mass selection from year to year may basically change the nature of a variety within less than a decade, as seems to have occurred in the variety

Stone Mountain. Such changes within a variety may lead to re-naming with a consequent increase in confusion. Witness the large number of names by which the Florida Giant or Cannon Ball is known today; some of the strains of this variety differ in some important characters, and a study and classification of the various strains needs to be made. Market preference and change occur, often difficult to explain. For years Florida grew the long, cylindrical Tom Watson variety and others like it; then almost overnight the round to short-round Cannon Ball became the favorite, and the long type melon was supplanted.

What may be an ideal watermelon from one viewpoint may be very different from another angle. That is, the plant breeder, the seedsman, the grower, the wholesale buyer and the final consumer may not always agree, and each is apt to want different things, all of which may not be possible to combine under one skin. Often we have to sacrifice one thing to get another, and our failure to appraise varieties has resulted in a great many varieties, each having a few good points but also marked defects. Many seedsmen would like to eliminate some of these varieties but seem unable to agree which will get the axe. We need a series of standards by which to judge a variety, and a brief summary with that purpose in view may not be out of place here. There may be omissions, and not all of the points are of equal importance, but a satisfactory compromise of most of them is necessary.

Watermelon Characters and Their Inheritance

The various characters that go to make up a variety may roughly be grouped under fruit characters and plant characters. Although plant characters often may determine fruit characters, a distinction is made because the plant characters are more general and may be hard to determine without a considerable amount of detailed work. On the other hand, fruit characters are specific and are easily determined by observation.

Fruit Characters. The main characters by which melon fruits are distinguished are size, shape, color and marking, thickness of rind, texture of rind, color of flesh, texture of flesh, uniformity, flavor, sugar content, seed size, seed color and number of seed. Some decision concerning each of these points must be reached, keeping in mind the purpose for which the melon is intended and the conditions under which it is to be grown.

The shape of a long melon should be a cylinder with ends square and well filled. For a round melon a slight "squareness" of the ends generally is liked. A number of years ago the demand was for a large melon, the larger the better; then came an era when a smaller melon was asked of the breeder, a melon adaptable to small families and small refrigerators; and today the demand seems to be again as it started, the bigger the melon the better. Even within a single State, at the same time, the demand can differ; Central Florida wants big melons, while around Tampa the Cuban population wants a relatively small, 12–15 pound melon, and a trucker peddling a load of big melons there has trouble disposing of his cargo. Uniformity in shape and size are more important than excessive sizes with variation of both size and shape. McKay (17) has shown that oblong and round shapes in melons seem to depend on single factor differences, while Porter (33, 34) believes that the inheritance of fruit shape is complex. Weetman (54) gives data to show that the difference between elongate and spherical fruits is determined by a single pair of genes which lacks dominance. Heterozygous individuals bear fruits of intermediate form. The shape of the mature fruit and young ovary shape were closely correlated. The small size of a mature fruit seemed to be dominant over large fruit, if data for fruit weight were plotted arithmetically, but if the data were plotted logarithmically the genes for size seemed to lack dominance and had proportional effects. Fruit shape and fruit weight were significantly negatively correlated. Poole *et al.* (22) have found that fruit shape and plant sex habit are linked with a cross-over value ranging from 0.136 ± 0.029 for a backcross population of 140 plants, to 0.207 ± 0.010 for segregating F_3 populations totaling 2,085 plants, to 0.350 ± 0.035 for an F_2 population of 301 plants. Fruit shape and fruit weight were significantly correlated in some crosses and backcrosses, but in others the two characters showed no significant correlation. Multiple-factor determination of weight prevented their making linkage estimates. The number of genes segregating for weight inheritance in the cross, Northern Sweet (about 3.2 kilos) x Dove (about 8.0 kilos, heterozygous for weight), was estimated from the F_2 population at 25 genes and from the backcross to Northern Sweet at 12 genes. Weetman (53) has shown that it is possible to forecast the mean shape of watermelon fruits by averaging a number of cotyledon indices, but that the probability of making accurate predictions for individual plants is considerably smaller. Round melons seemed to produce round shaped cotyledons, and more elongate cotyledons were correlated with elongate melons. With citrons there was no correlation, negative or positive, between cotyledon shape and fruit-shape, and in a group of watermelon-citron hybrids the coefficients were not significant.

The chief points to be considered in connection with the color and markings of watermelons are the market preferences, the type the growers have become accustomed to, and more especially the relation of color to the likelihood of sunburn. Ordinarily it may be said that the darker the rind the more the likelihood of sunburn and *vice versa,* but some of our light-skinned melons also burn rather easily. There is a definite prejudice against the lighter colored rind (*e.g.,* the Hawkesbury) in some sections, while in other sections this color is preferred over all others (*e.g.,* the Smithfield area of Virginia). Porter (33) has found that green fruit skin is dominant over yellowish white but incompletely dominant over striped and yellowish green, while Weetman (54) reports that dark-green rind is dominant over light-green rind by a single factor difference, though other genes appear to determine minor variations in the light color; broad striping seemed to be due to a single recessive factor in one cross, but was dominant in another cross. The gene for striping either forms a multiple allelomorphic series with the genes for dark- and light-green rind color, or is closely linked with these genes. McKay (17) observed what he thought was a 3 : 1 ratio in the case of "green stripe" *vs* "white-stripe" melon fruit markings, but further work was considered necessary.

Thickness of rind is rather variable, but the aim should be to produce as thin a rind as possible consistent with the ability to stand handling and shipment. While the rind must be thin, it must also be tough; one easily cut with average pressure from a thumbnail is not tough enough under ordinary conditions. A half inch of extremely tough consistency is about the ideal, but this would also call for great improvement in handling in the field. Melons often are handled as if they were pulpwood; and such handling may result in many melons becoming pulp unless they have a number of the characters of wood. Porter (33) has shown that tough rind is dominant over tender rind, a single-factor difference being indicated from a 3:1 segregation in F_2.

The ideal flesh color of a watermelon to most people is deep rich red, but there is a wide range from brilliant red to yellow. Yellow fleshed melons do not have a general appeal, but some people like this type of flesh. The writer recently has seen a shade given a local name of Flaming Delicious; the flesh has the appearance of half-cooked steak with a dash of orange added. Bennett (2) states that red flesh color appears to be dominant over white flesh color, but in his F_2 there appeared more white-fleshed individuals than expected, and the backcross to the white parent gave all white-fleshed fruits. Porter (33) states that red flesh color is dominant over yellow and suggests the symbol "R" for red and "r" for yellow.

Texture of the flesh is as important as the color. Some varieties are grainy, some rather slimy, and it is the work of the breeder to secure a blend of characters that will satisfy as many people as possible. Crispness and freedom from stringiness are perhaps the main requirements. Bennett (2) could find no evidence of the inheritance of flesh texture in watermelon, and Porter (25) believes that the flesh quality of citrons resistant to Fusarium wilt is dominant over the flesh quality of the wilt-susceptible watermelon, as Orton (19) had stated previously. There is considerable range of variation in the uniformity of flesh in regard to both color and texture. In some melons the range is all the way from small, hard areas within the flesh to whiteheartedness and inedibility. It is probable that much of the whiteheart of melons is due to genetic rather than environmental causes, but of course this should be qualified on the basis of the definition of whiteheartedness. The so-called "second growth" of watermelons should not be confused with whiteheart. "Crackleheart" may occur also to a greater extent in some strains than in others and must be guarded against. Its origin is poorly understood, but it is possible that both environmental and genetic factors are responsible. Round varieties seem to show this defect more often than long varieties, and it is possible that the difficulty may be to some extent mechanical in that distribution of weight is less efficient in round types. Walker (46) reports that whiteheart was present in the Kleckley Sweet out of which he selected the wilt-resistant Leesburg; melons showing whiteheart were discarded, and the Leesburg is free of this defect, as is the Blacklee, while the Hawkesbury, the other parent of the Blacklee, shows much whiteheart (51).

✓Flavor in watermelons in judged largely on the basis of sugar content, but different flavors do occur and some are objectionable but relatively easy to eliminate. The sugar content is more important and takes continual testing to assure that the variety possesses a total solids content of more than nine percent when mature; the higher quality melons will range between ten and twelve percent, sometimes reaching sixteen percent. Sugar content does not necessarily have to be associated with flesh color, since tests on relatively immature melons can show rather high refractometer values. This might be an advantage when melons are marketed before complete maturity. Porter *et al.* (35) found that real differences in sugar content exist among melons, with Leesburg and Hawkesbury relatively low in California and the Klondike types relatively high. Eighty-five percent of the total soluble solids is sugar, and it is justifiable to use the hand refractometer to determine relative sweetness of juices of melons. Two or three drops of juice taken from the blossom end of one-half of a fully mature fruit, between the rind and the seed zone, gives approximately the same refractometer reading as a composite sample taken from the edible tissue located almost entirely within the seed zone of the same half. The center of a melon has a soluble solid content roughly 1.3 percent above the average (16). Reducing sugars are formed first in the watermelon, and with approach of maturity sucrose development proceeds rapidly (35). Sucrose predominates in overmature or mature stored fruits. Of the reducing sugars, levulose predominated over dextrose in limited tests; later dextrose increased more rapidly than levulose. Varieties possessing relatively low soluble solids and total sugar content on the average contain individual plants which produce high sugar fruits.

There is a wide range in the size of seed in melons, and little effort has been made to breed to any particular size. From the consumer's standpoint he would just as soon have as few seed as possible. The color of the seed is a matter concerning which there is more difference of opinion; darker seed usually are preferred and a red flesh color is intensified by the presence of dark colored seed. Some persons believe, incorrectly, that lighter colored seed, white or tan, are signs of immaturity or crossing with citron. Another rather wide range is the number of seeds produced by varieties, and a somewhat high price charged per pound can be traced in certain instances to the production of relatively few seeds per melon. Environmental influences are said to determine the number of seeds produced, but experimental evidence is lacking. Poole *et al.* (21) in a well-rounded study found that seed coat color ranges from an almost pure white through red, green, tan, mahogany and black, with various patterns superimposed. Their new term "clump", referring to seed color, means a phenotype which varies in segregating populations from a large central eyespot to nearly uncolored seeds except for black spots on the hilum prominences. They studied black, clump, tan, white-tan-tip and white-pink-tip seed color phenotypes, and of ten possible cross combinations seven were made. Analysis of F_2, F_3 and backcross populations indicated that the colors and patterns of this series were determined by the interaction of a system of three main genes, R, T and W, and one specific modifier, D, operating on black only. Of the eight possible phenotypes from the three main genes, six were indicated, *viz:* RTW (black), RTw (clump), RtW (tan), Rtw (white-tan-tip), rtW (red) and rtw (white-pink-tip). RTWd restricts the black pigment to dots more or less uniformly distributed. There was no evidence of linkage within groups of the length (LS) or color (DRTW) genes; but between groups, the genes L and W displayed coupling linkage of 19.3 ± 1.1 in F_2 and 15.8 ± 1.2 in back cross, 24.7 ± 4.9 repulsion linkage in F_2, and 21.52 ± 7.24 coupling linkage among the two completely identified parents of an F_3 generation. The previous works of Kanda (12) and Weetman (54) support these findings. Other works on the inheritance of seed color are by McKay (17) who showed in two crosses, tan × red and green × red seed coat, that the red color is recessive and controlled by a single factor difference, and by Porter (33) who reported that black and tan seed coat each are dominant over white, black is dominant over tan, red seemed to be dominant over white, and both black and red seemed to be dominant over green. The number of factors involved was not determined. Weetman (54) crossed races of melons wherein weight samples of 25 seeds were light (1.22 ± 0.01 gm.) and heavy (2.60 ± 0.05 gm.). In the F_2 and backcrosses to both parents the lighter weight parent approached monogenic dominance over the heavier, but chi-square analysis failed to establish an acceptable fit. Poole *et al.* (21) found that watermelon seed length can range from 5.5 to 15.5 mm. Three seed-length phenotypes were studied, short (average about 6 mm), medium (average about 10 mm), and long (average about 13 mm), which behaved with respect to each other as though belonging in a dihybrid F_2 segregation of nine medium (LS) to three long (lS) to four short (Ls and ls). Weetman (53) calculated an index for seed shape and showed that melon varieties with round fruits have seeds which are less elongated than those from long-fruited varieties.

No evidence of linkage has been found between flesh color and seed coat color, between flesh color and fruit rind color, between flesh color and rind toughness, between fruit-skin color and rind toughness, between seed-coat color and rind toughness, or between skin color and seed coat color (33).

Plant Characters. The chief points are vigor, earliness, prolificacy, and resistance to disease, insects or mechanical injury. Vigor may be defined as the ability of a variety to thrive under a wide range of environmental conditions, the aim being to secure strains or varieties that show an ability to survive without special care. It may take a long time to gain definite information on what constitutes earliness, which is of great importance in early market sections (Florida, Georgia), but no variety, to succeed, must be conspicuously later than others grown in the same geographical area. Earliness may be associated with vigor, and this might also be said of prolificacy. In some instances a variety may be overly prolific, *e.g.*, the Blacklee, and require heavy "pruning" which is expensive, with the possible introduction and certain spread of plant diseases in the process.

Inbreeding of the watermelon does not cause loss of vigor, self-sterility, decrease in number of fruits, or total yield per plant (28, 31, 46, 51), and tends to isolate strains which produce either larger or smaller fruit than the commercial variety, and to establish homozygosity for those factors responsible for rate of plant growth (31). In the Klondike variety, strains inbred for four successive generations have been isolated which produce fruits equal in weight to those of the parent variety but which excel the latter in fruit uniformity, flesh color, texture and quality (28). In 1947 the Iowa Agricultural Experiment Station released two melon varieties, the Dixie Hybrid and the Kleckley Hybrid, both F_1 seed, the former wilt-resistant, the latter possessing "strong resistance to wilt and anthracnose". It is pointed out that seed of these melons should not be saved, since they do not reproduce themselves. The two varieties were grown at Leesburg in 1947, and some wilt occurred in the Dixie Hybrid which is a large, well favored and tasty melon; the Kleckley Hybrid, late to mature and rather small, showed more anthracnose than Black Kleckley and was not tested for its resistance to wilt. This is probably the first instance of the usage of hybrid seed in watermelon. Porter (31) and Walker (49) have described the techniques valuable in watermelon breeding.

Rosa (37) and Porter (33) have shown that in crosses between monoecious and andromonoecious varieties of watermelons, the monoecious condition depends on a single dominant factor. In watermelons and citrons the monoecious condition predominates, and only a few (Black Seeded Angelino, Black Seeded

Chilian, Snowball, Winter King and a Kalihari citron) have been found to possess hermaphroditic flowers. The factor concerned in sex differentiation must be borne by both micro- and macro-gametes, since reciprocal crosses and back-crosses give concordant results (37). Pistillate flowers usually have a long ovary, while hermaphroditic flowers have shorter, more nearly round, ovaries. Kozhukhow (13) reports 11 pairs of chromosomes for several varieties of commercial watermelons, and Bennett (2) confirmed this figure.

Fruit setting tendency, following artificial self-pollination, is apparently influenced by the air temperature and humidity between 6 A.M. and noon, by the hour of pollination, by ovary size and by the relative vigor of the runners bearing the selfed flowers (31). Relatively low air temperature and relatively high humidity from early morning until noon favor fruit setting. A better set is obtained if pollinations are made between 6 A.M. and 9 A.M. than between 9 A.M. and 12 noon. Small ovaries rarely set fruit, while fruit setting tendency progressively increases among large ovaries. Strong or medium runners bear large ovaries. There is no evidence that fruit-setting tendency, after self-pollination, is heritable; it depends entirely upon proper selection of the pistillate flower with respect to ovary size and runner vigor and on the environmental conditions for a period of five or more hours after pollination. No evidence was found of flowering peaks or fruiting cycles, such as have been reported for muskmelon and for squash.

Resistance to disease is highly important, and we now have a number of wilt-resistant varieties (see: Fusarium Wilt), and at least one anthracnose-resistant variety (see: Anthracnose), but no known varieties resistant to gummy-stem blight or downy mildew. Resistance to aphids will be acceptable when found, and resistance to the attacks of the root-knot nematode could be used. Under the heading of mechanical injury must be considered sunburn which can severely injure an otherwise beautiful crop of melons. Sunburn in Florida seems to occur under conditions of high temperature and high humidity; the small area of melon rind uppermost literally burns and dies, leaving a yellow blemish which can serve as an avenue of entrance for rot-producing organisms. Locally we have found that a lime wash or paint, applied to the uppermost strip of tissue of the melon, not more than three inches wide, will at low cost reduce or inhibit burning. Its removal is easy with a dampened rag. Excessive or repeated rains may wash off much of the lime, but it can be replaced even more rapidly than originally applied. Failure to show much sunburn is one of the good points about the variety Cannon Ball.

The most elusive factor in melon breeding is the matter of market preferences in which the range is about as great as the number of consumers, and it often is difficult to fix upon definite standards because of the constantly changing demands of both grower and consumer. Even with the best of varieties, seasonal conditions or diseases may undo the most careful work of the breeder or seedsman. With the improvement of varieties and of seed there also should be an accompanying improvement in field practices, particularly in disease control and handling.

Even though a happy blend of most of the varietal characters is attained, the problem arises as to how to maintain the variety unchanged, or at least prevent its deterioration. It is not possible in most cases for wholesale seed growers to assume full responsibility, since few are in a position to maintain breeding fields where close attention can be paid to a single variety. About as far as they can go in this direction is their cooperation in carrying out a satisfactory certification program. Where disease-resistant varieties are concerned, a lack of detailed knowledge of the diseases involved would be an especial obstacle. Without sacrificing the more detailed work of varietal testing and improvement it is not possible for State experiment stations to maintain indefinitely stock-seed fields of standard varieties or of new introductions. While much work is being done toward improving varieties and seed, no long time provision has been made to assure the maintenance of stocks we now have and the ones that will appear in the future. It seems that some provision of this kind is needed, one that would serve as a repository for unquestionably pure and true types of standard and recognized varieties and strains. Testing and accurate appraisal of all stocks would be made before recognition. Maintenance of such stocks certainly would simplify seed certification. In the meantime, certification of seed, purification of stocks, elimination of the less desirable strains, development of new strains and the improvement of older ones are going ahead in various parts of the nation.

Breeding For Disease Resistance

When one examines the literature on watermelon breeding, two things immediately focus the attention, one, that most of our knowledge of the inheritance of characters in watermelon has been obtained by plant pathologists or plant breeders interested in the development of disease-resistant watermelons, and second, that the States most interested in the production of resistant varieties are the States that have contributed to our knowledge of the genetics of watermelon. Because a variety not only must be resistant to disease but must also possess high quality and be desirable in type, the watermelon breeder usually has studied the factors that determine quality and plant type simultaneously with the mode of inheritance of disease resistance. In a few cases horticulturists, geneticists or plant breeders have studied the watermelon *per se* (12, 17, 37).

Investigators have striven to develop varieties resistant to wilt, caused by *Fusarium oxysporum* f. *niveum* (E.F.S.) Synder and Hansen, and to anthracnose, due to *Colletotrichum lagenarium* (Pass.) Ell. & Hals. Other diseases that would appear susceptible to control through breeding are downy mildew, caused by *Peronoplasmopara cubensis* (B. and C.) Rost., and gummy-stem blight, due to *Mycosphaerella citrullina* (C. O. Smith) Gros.[1], for differences in susceptibility do exist.

Fusarium Wilt. The fungus *Fusarium oxysporum* f. *niveum* (= F. *niveum*) was first associated with watermelon wilt by Erwin F. Smith in 1894 who studied the disease in South Carolina (41). Later Smith (42) found the macroconidia and chlamydospores, and in 1899 he gave a report on the morphology, vitality, longevity, pathogenicity and dissemination of the causal agent, a description of some of the seedling and field symptoms, and an account of the relation of the fungus to the host (43).

Wilt-resistant Varieties. Orton's research (19) is a classic example of the early work in this country in the development of disease-resistant plants. His Conqueror variety, produced in eight generations from the cross of the wilt-susceptible, edible variety Eden with the wilt-resistant, inedible citron, seemed to be highly resistant at first, but subsequent testing showed that its disease-resisting powers were lacking in Iowa (25, 26, 27, 30), West Virginia (39, 40) and Oregon (40). It was highly resistant, however, in Texas (44), but its type and quality there were not entirely desirable (26, 44). Today the Conqueror seldom is grown. Orton did demonstrate, however, that the citron melon possessed resistance to Fusarium wilt, and this lead was adopted by investigators in Iowa, California and elsewhere.

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[1] A recent paper (Chiu, W. F. The pathogenicity of *Mycosphaerella citrullina*. Phytopath. [Abst.] 38: 5. 1948) states that Improved Kleckley Sweet is more resistant than Hawkesbury.

In 1924 the Iowa Agricultural Experiment Station initiated a program to develop watermelon varieties resistant to Fusarium wilt which had wrought so much damage, particularly around Muscatine, that fields once producers of good crops had been idle for 16 years. Land values there dropped materially and the watermelon section lost its air of prosperity, a condition that was charged directly to watermelon wilt (26). The disease is said to have reduced the average annual Iowa acreage by 90 percent and the average annual shipments from about 3,000 to less than 50 carloads (30). Porter and Melhus soon recognized that in every infested field a few plants of the varieties Kleckley Sweet, Excel and Long Light Icing did not wilt (30), and in 1927 they planted a large field of the Kleckley Sweet on infested soil, out of which 11 selfed melons were obtained, and one of these, the K-S4, became the Pride of Muscatine. This variety, while it served to tide over the Iowa farmers, was not desirable in type and had a rather inferior flesh (34, 56). By further selection and inbreeding of another strain from Kleckley Sweet, the K-11, the variety Improved Kleckley No. 6 was isolated and introduced around 1936. Out of the cross Stone Mountain x Japan No. 7 (a wilt-resistant, round-fruited, yellow-skinned, white-fleshed variety) was developed the wilt-resistant Improved Stone Mountain No. 5 (23) which is adapted for local marketing and home use rather than for shipping because of its tender rind. Two other wilt-resistant varieties, the Iowa Belle and Iowa King, were developed in Iowa during a three-year period prior to 1931. Both of these were chance hybrids out of Orton's Conqueror which had been subject to pollination by other varieties, particularly the Kleckley Sweet, picked up in the field by O. H. Elmer and S. M. Dietz and turned over to Porter and Melhus for further study (30). Both Iowa Belle and Iowa King are long type melons; both mature later than Pride of Muscatine. Layton and Wilson have shown that Pride of Muscatine, Iowa Belle and Iowa King give good yields on Fusarium-infested land (14).

Continuing his research at Iowa, Porter (25) reported that some Chinese selections, Preserving Citron, and two selections of forage melons from Africa possessed resistance to wilt and were being utilized as parents in his breeding program. At about the same time Sleeth (40) was finding that a Russian variety of melon was almost immune from wilt. Porter and Melhus (27) then tried crossing the Conqueror melon with the Kleckley Sweet and reported that the F_3 of some of the crosses appeared to possess considerable resistance. They noted, however, that the Conqueror showed little resistance, and this confirmed previous observations that resistance was present in the Kleckley Sweet; Walker (46) corroborated this, and his Leesburg is a selection out of Kleckley Sweet. Porter and Melhus (27) also tested the resistance of seven citron strains, finding that six were immune from wilt and that in the F_3 of the cross Kleckley Sweet x Citron (variety Kafir) there was 86 percent resistance, but few of the melons were edible.

In the meantime the watermelon growers of central Florida (Lake County) had secured an appropriation from their legislature to establish a research laboratory at Leesburg to develop a melon or melons that would resist Fusarium wilt. The predominant variety in 1930, the year that the Watermelon Laboratory was started at Leesburg, was Tom Watson, which is a high quality, cylindrical, dark rind variety with brownish seeds. Florida melon growers were afraid that they would soon exhaust their supply of "new land", or their supply of land which had not supported melons for eight to ten years, that is, land on which a wilt-susceptible variety could be grown. Clearing and fencing new land each year involves heavy expense (over $40.00 per acre in 1946), and, as the fields become located farther from the highways and railroads, there is also an increase in the costs of transporting equipment, labor and the crop. Walker (46) stated in 1936: "The continuous use of new land in the Leesburg area has practically depleted the supply and, unless a marketable, resistant variety is grown, the industry in this particular area must decline". This did not turn out to be so, however, and even today the watermelon grower of central Florida seems to be able to find "new land" on which to plant his wilt-susceptible favorite variety, the Cannon Ball or Florida Giant. Walker (46) pointed out further that the wilt-resistant varieties developed by the Iowa Station were not suited for Florida growing and marketing conditions, which necessitated the production of a wilt-resistant variety for Florida. He tested the wilt resistance of 104 varieties and strains of watermelon and also a few citrons. To speed up the work of strain elimination, greenhouse testing of resistance to wilt was carried on simultaneously with field work. By 1936 Walker had eliminated all but about 12 strains of melons, one of which was the high-quality, wilt-resistant Leesburg variety, obtained by selection from the Kleckley Sweet, seeds of which had been obtained from a Leesburg seedstore (46). The Leesburg is of a lighter color than the Kleckley Sweet but with a tougher rind, long, with blocky ends, smooth, faintly grooved, medium dark green. The seeds are white. It was free of whiteheart and did not sunburn too much, averaging 22 to 26 pounds in weight, occasionally reaching 30 to 35 pounds.

Unfortunately the Florida watermelon growers did not like the Leesburg variety; they said it was too small, the flesh was pale red instead of red, and it had white seeds, qualities which are objectionable because they often are considered to indicate immaturity. So, with plenty of "new land" available, the Leesburg went unused locally, but it was tried in Virginia (4, 5), Oklahoma (3), and California (34), and was found to be highly resistant. In none of these places, however, was it the type required and it could not compete with varieties like the Hawkesbury or the Klondike. Seedsmen in north Florida still grow Leesburg seed which they market in Florida, Georgia, Mississippi, Maryland and Virginia, but they sell only about 10 percent of the seed they sold in 1942. The Hawkesbury had been discovered in Australia in 1935 (59, 60), growing in a field of Grey Monarch melons, by Mr. H. S. Shirlow, the plant breeder at the Hawkesbury Agricultural College, Hawkesbury, New South Wales. Since it differed from the regular Grey Monarch in that it had dark instead of light colored seed, it was first named "Dark Seeded Grey Monarch". Later it was identified wrongly as the Thurmond Grey variety and because of its resistance was designated "Wilt Resistant Thurmond Grey". Subsequently it was found to be different and was named "Hawkesbury Wilt Resistant" or "Hawkesbury". First to receive this wilt-resistant variety in America was Duke Layton at Iowa, and from Layton it was sent to H. T. Cook at

Norfolk, Virginia. Cook (4, 5) and Cook and Nugent (6) confirmed that the Hawkesbury is highly resistant to wilt, as did Walker (51) who used it to cross on Leesburg to obtain the Blacklee, and others (3, 34, 38). Porter (34) reports that he isolated a wilt-resistant white-seeded strain of Grey Monarch in 1930, but it was of inferior quality. Continued inbreeding of more desirable resistant individuals found in Grey Monarch resulted in the production of a strain with 68 percent resistance. Cook (4, 5) and Cook and Nugent (6) were pleased with the performance of the Hawkesbury on wilt-infested land in the Smithfield area of Virginia, but less pleased with the varieties Leesburg, Pride of Muscatine, Iowa Belle, Iowa King, Improved Stone Mountain No. 5, Improved Kleckley Sweet No. 6 and the wilt-resistant strains of Klondike that Porter was developing for the California melon growers. The Smithfield growers like large grey melons, so the Hawkesbury suited them perfectly.

About 1931 Porter left the Iowa Agricultural Experiment Station and went to California which needed wilt-resistant watermelon varieties. The Klondike is their most desirable variety, an oblong to long melon, black-seeded or brown-seeded, depending on the particular strain encountered, with slightly ribbed, dark-green rind, which originated about 1908 as a mutation in a field in southern California (31). A variation of the Klondike is the Striped Klondike which has a light-green rind with darker-green striping, said to have been selected about 1923 in a field of commercial Klondike. To develop resistance to Fusarium wilt in the Klondike, Porter (34) planted a wilt-infested field with approximately 200,000 seeds of the variety obtained from as many sources as possible. Sixteen plants survived, and self-pollinated seed was saved from nine plants which were used as subsequent breeding stocks; in 1937, after two years testing, only a single strain seemed worthy of further propagation ("Pedigree 24"). This strain, later termed "Klondike R 16," showed high resistance in California, Iowa, Florida, Georgia, Virginia and Indiana. The flesh texture left something to be desired but this defect was not pronounced in Georgia and Florida. In greenhouse work a large number of plants of the susceptible Klondike were grown in wilt-infested soil; 12 plants out of 2790, or less than 1 percent, lived, and but a single strain was obtained with a high resistance which was inferior in quality to Klondike R 16. Porter next tried hybridizing commercial Klondike and the inbred Klondike lines initiated by the late Dr. J. T. Rosa with the resistant Conqueror, Pride of Muscatine, Iowa Belle and Iowa King, of which Iowa Belle proved to be the most valuable parent. From the cross Klondike × Iowa Belle came "Klondike R 7" which was distributed to California growers when in its F_7 generation; in addition to wilt-resistance, both Klondike R 16 and Klondike R 7 possess a higher sugar content than commercial Klondike (35). With their release the problem of controlling Fusarium wilt of watermelon in California was licked.

In Florida the problem has not been so easy of solution, and today the melon growers have no wilt-resistant variety that they like and will use. As soon as Walker realized that his Leesburg was not liked, even though highly resistant to wilt, he crossed it with Hawkesbury. Both parents being resistant to Fusarium wilt, it was possible to select for horticultural characters in the second generation. By 1942 the new variety, the Blacklee, a long, relatively large (25–30 pounds), dark green, faintly grooved melon with seeds that appear to be jet black when wet but on drying show themselves to be densely stippled with black, a character rather unusual in watermelons, of superb quality, and 70 to 75 percent resistant to wilt, was released to growers; in 1944 came the official description (51). Sometime prior to 1937 there appeared on the watermelon scene a variety which has been variously termed Cannon Ball, Florida Giant, Clara Lee, Black Diamond, *etc.*, a short-round to round, thick-rind, faintly to markedly grooved, rather large (30–40 pounds), dark-seeded variety of marked earliness, a feature which endears it to growers in Florida and elsewhere in the southeastern States. In comparative tests, Cannon Ball, as it is most generally termed in central Florida, will outperform Tom Watson, Dude Creek, Dixie Queen, Garrison, Leesburg and Blacklee by seven to 14 days, depending on the season. The Blacklee seems to be at its best in seasons of low rainfall, perhaps because of its wilt-resisting character, but year after year the Cannon Ball, which does not sunburn as easily as Blacklee, is preferred, though there is no question but that the Leesburg × Hawkesbury progeny is superior in quality of flesh. In 1947 less than 100 acres of Blacklee were planted in Florida. Elsewhere Blacklee is liked, and its high quality and wilt resistance are used by growers in the Carolinas, Virginia, Maryland, Missouri, Oklahoma, Arizona, Texas and other States.

Other wilt-resistant varieties, still unreleased, were developed by Walker out of the Leesburg × Hawkesbury cross, the Brownlee, and the Improved Leesburg, which resemble the Blacklee except for the brown seeds of the former and white seeds of the latter, and the unnamed 124–402–019 which favors the skin-color of the Hawkesbury. These three varieties, like Blacklee, are late maturing as compared with Cannon Ball. In this connection it may be interesting to report value from selection within an apparently pure line. The Brownlee, already breeding true by 1941, was continued to be inbred for two more years, and in 1943 several selections were made by a foreman unfamiliar with the oft quoted remark, "selection within a pure line is time wasted". This man, Mr. Loren H. Stover, made his selections on the basis of quality and size, but in each case the individual melons happened to be among the first maturing in the field. So, in 1945 there were three strains of Brownlee in the Leesburg melon collection, the original and two selections from it. All three were planted in 1945 by the writer, then new at the Leesburg laboratory, in order to familiarize himself with the melon-breeding records. Both selections are earlier maturing than the original Brownlee which has been discarded, and the present Brownlee consists of bulking of the two selections. This laboratory is now determining whether the Blacklee is a "pure" line for earliness or whether an improved strain can be obtained by selection for this "character", for there seems little doubt that an early Blacklee would be acceptable to Florida growers who some day will have to plant wilt-resistant varieties.

In 1942 the Georgia Experiment Station introduced their Georgia Wilt-Resistant melon, developed by van Haltern (45) out of the cross Cuban Queen × Iowa Belle, which in general external appearance resembles Stone Mountain. The chief objection to the variety is its small size as compared with the larger Cannon Ball. A second selection of van Haltern's is his Georgia Wilt Resistant No. 2 which looks more like a pumpkin than like Stone Mountain, but it is by far the sweetest melon grown, with the exception of the Klondikes. The rind is thin and cracks easily in wet weather. Epps (8) more recently has released the wilt-resistant variety Miles, developed at the Tennessee Agricultural Experiment Station from material sent there from the Mississippi Agricultural Experiment

Station in 1942. The Miles originated from the cross Dixie Queen × Klondike; it is oblong, green with darker green stripes, with a tough rind, white-seeded, 25–35 pounds in size. Another melon variety is the wilt-resistant Dixie Queen which the writer tested at Leesburg in 1947 and found to be about as resistant as the Blacklee, but which was less resistant at Charleston, S. C.[2] This wilt-resistant Dixie Queen is said to have been found in Nebraska about 1943 and is being commercialized by Otis S. Twilley, grower of watermelon seed at Salisbury, Maryland. In 1946 the variety was planted by Mr. W. H. Thomson, seed grower, of Lloyd, Florida, on wilt-infested land where it showed a high degree of resistance.

At Charleston, S. C., in the Regional Vegetable Breeding Laboratory of the United States Department of Agriculture, research developing anthracnose- and Fusarium wilt-resistant melons has been under way for a number of years under the joint direction of C. F. Poole and C. F. Andrus, and lately of Andrus alone. To date no publication has been forthcoming on their results, but this writer, and possibly others, has received seeds of segregating material for trial. At Charleston has been attempted the production of wilt-resistant Garrison and Dude Creek varieties, using Leesburg and Hawkesbury as resistant parents.

Physiologic Strains of Fusarium. While it was thought for a time that different physiologic forms of the wilt fungus must exist (39, 40), since the Conqueror variety was not resistant in all melon-growing areas, present ideas are that pathogenic variation among strains of *F. oxysporum* f. *niveum* probably has not been, to date, a serious factor in the breeding programs undertaken (34). It is significant that Walker (46, 48, 51), in his development in Florida of the Leesburg and Blacklee varieties, does not report the use of isolates of the wilt fungus from other States, yet both varieties are wilt-resistant wherever tested. Sleeth (40) has shown, and Bennett (2) has confirmed, that the amount of wilting produced by a given strain of the Fusarium is not always uniform when tested against different varieties of watermelon. The cause of muskmelon wilt (*Fusarium oxysporum* f. *melonis* Sny. and Hansen) is said not to attack watermelon, nor does the watermelon pathogen attack muskmelon (10), but recently Hendrix *et al.* (9) report that some isolates from wilted muskmelon plants can cause pre-emergence killing and wilting of watermelon seedlings, and some isolates of watermelon parasitize muskmelon. In general, the virulence of an isolate was greater on its original host than on the second host plant, but several isolates from watermelon caused a more severe reduction in stands of muskmelon than of watermelon.

Inheritance of Resistance. Until recently it was thought that resistance to Fusarium wilt is inherited as a recessive character, since F_1 plants become diseased when grown on wilt-infested soil. Segregation of resistance and susceptibility takes place in the F_2 generation, but no one has obtained clear cut or established ratios (2, 19, 25, 30, 48). In these instances wilt resistance was obtained from a citron (*e.g.*, Conqueror) or from the progeny of a citron × watermelon (*e.g.*, Iowa Belle or Iowa King). First clue that wilt resistance might be inherited differently was found by Welch and Melhus (52) who crossed resistant × susceptible watermelons and discovered that the F_1 progeny were not always susceptible to wilt. In one cross, Dixie Queen × (Iowa Belle × Jugoslavia 7 × Iowa Belle), the F_1 were 70 to 85 percent resistant, and in two other crosses, (Japan 7 × Thurmond Grey and Japan 7 × Dixie Queen) the F_1 were 80 percent resistant. In ten other crosses the resistance ranged from 50 percent to zero with the susceptible parent grown as a check dying 100 percent. Resistance is considered by some to be multifactorial (2, 34; unpublished data by Walker), and because of difficulties incident to this fact no wholly immune or 100 percent resistant variety of watermelon is yet available. The highest degree of resistance seems to be 75 to 80 percent. However, under ordinary field conditions of wilt infestation this is practically 100 percent, as a considerable number of seed are planted and by the time the plants are thinned, most of the susceptible individuals are dead or dying. Were resistance due to a single factor which is inherited as a recessive, then complete resistance should be found in the immediate progeny of a selfed plant of a commercial variety that withstood the fungus. No such case has been reported.

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[2] Personal correspondence with Dr. F. S. Jamison, Horticulture Department, Florida Agricultural Experiment Station, Gainesville, Florida, and Dr. C. F. Andrus, Regional Vegetable Breeding Laboratory of the United States Department of Agriculture, Charleston, S. C.

No close linkage exists between resistance to Fusarium and flesh color, fruit shape or color of seed (2).

Measuring Wilt Resistance. It was realized early in the development of wilt-resistant watermelons that information regarding infection by the fungus was inadequate. More had to be known of the symptoms associated with wilt, how to reproduce the disease, and how to test the wilt resistance when obtained. Such questions arose as: "Are results in the greenhouse comparable to results obtained in field tests?" "How many seeds should be planted in a hill?" "In a pot?", and so on.

Smith (43), Taubenhaus (44) and Orton (19), the pioneers in watermelon wilt studies, all described the symptom "wilting", but it remained for Porter (26) to show that the fungus also could cause seedling wilt, seedling rot, damping-off, stunting and root canker, also leaf chlorosis and a shortening of the internodes of diseased vines accompanied by excessive blossoming at the ends of the runners (30). The fungus was found to grow best on artificial media at 24° to 32° C., with a minimum below 12° C., and a maximum above 25° C. (26), and various strains give good growth on agar between 20° and 33° C., but 26° to 28° C. is most favorable (48). In the field mature plant infection is greatest when the soil temperatures are 22 to 27° C., with seedling rot most severe at 16° to 18° C., and seedling wilt most severe at 25° to 28° C. (30). Greenhouse studies (48) revealed that infection of watermelon or of citron takes place between 21.5 and 30° C., with 27° C. the most favorable; seeds rot when the soil temperature is 18.5° C.

A number of investigators have attempted to measure relative resistance of varieties and hybrids in the seedling stage in the greenhouse (2, 30, 34, 40, 48, 58), but to date the techniques used and the results obtained are not accurate enough to be dependable, even though they show general agreement. Often, when melon seeds are planted in naturally wilt-infested soil, such organisms as *Pythium* spp. and the root-knot nematode (*H. marioni*), produce, with the Fusarium, an infection complex which is difficult to separate into its component parts. If steamed, later Fusarium-infested soil is used, virulence may be many times as great as would occur in nature. These data are inadequate to give us a clear picture of the nature of the inheritance of resistance to wilt. Infection in the greenhouse has been obtained by the use of infested soil (26, 30, 46, 48, 58), by means of spore suspensions of the fungus injected with a hypodermic needle into the hypocotyl (26), and by insertion of mycelium into wounds (26). The fungus has been recovered from primary, secondary and tertiary roots, from stems, petioles, leaves, peduncles, and melon flesh and seeds of infected plants; unfortunately supposedly immune citron vines also have yielded a fungus pathogenic to watermelon, and from the vascular system of outwardly healthy watermelon vines the fungus can be cultured (26). With wilt-resistant varieties that have borne abundant fruit, if individual plants are examined carefully, 100 percent internal infection can be detected, yet such plants outwardly appear healthy, and self-fertilized seed from them will produce resistant plants. If a runner of a plant growing in wilt-free soil is induced to root in infested soil, only that portion beyond the new roots manifests infection. Again, if a runner is rooted in wilt-free soil while the main root system is in infested soil, the rooted runner may remain healthy (34).

Porter (30) found that inoculum was effective when mixed with steamed soil at the rate of 2:700 grams. The soil consisted of a mixture of two parts bench soil and one part river sand, steamed three times at 25 pounds for three hours on alternate days. One half pint of this soil is placed in a four-inch pot, and two grams of finely powdered inoculum of the fungus applied in a thin layer at the soil surface. The pot is then filled to within one inch of the top. Twenty-five surface disinfected seeds are planted and covered with steamed soil. Walker (46, 48) grew plants in the greenhouse and in the field in naturally and in artificially infested soil. In greenhouse work sterilized soil was infested with the wilt organism by mixing with the surface three inches of soil, in pots or cans, approximately a teaspoonful of agar cultures macerated with clean sand, or by adding a heavy spore suspension of the organism from steamed oat cultures, or by filling the upper third of the containers with soil mixed with sand-cornmeal cultures of the wilt fungus. The sand-cornmeal mixture was made up of equal volumes of sand and cornmeal moistened with tap water. The mixture, after cooking in an Arnold sterilizer for half an hour, was rolled into small balls about ¾ inch in diameter and placed in quart Mason jars to about two-thirds their capacity. After pressure sterilization the jars were inoculated with small quantities of a spore suspension of the wilt organism, and incubated two weeks at room temperature. Plants were observed in the greenhouse for 20 to 30 days, taking daily records on the development of wilt. In the field Walker reports that one or more applications of a handful of heavily infested soil to each hill insures good infection; plants were counted frequently during their growth until maturity, and a final check was made at the end of each season by cutting surviving vines and examining for wilt infection (46)[3]. The number of seeds planted per pot and the number of seedlings crowded into a hill can affect the number that die from wilt; the greater the number, the more that die, then the lower the apparent percent resistance (34). Wilson (58) modified the Iowa method (30) for greenhouse testing of wilt resistance by planting five seeds of the melon whose wilt-resistance was desired and an equal number of a wilt-susceptible variety in opposite sides of a four-inch clay pot, in steamed soil, in duplicate or triplicate. A level teaspoonful of wilt-infested soil is previously stirred into each pot at the one-third level. The soil inoculum is prepared from steamed soil later heavily dosed with a mixture of Fusarium cultures in which susceptible plants have been grown until all wilted. The seedlings are counted at emergence, six to nine days after planting; the wilting plants, at one to four day intervals, removing the diseased individuals as observed. Wilson believes that a greenhouse technique for testing resistance applicable to one resistant variety may not be equally usable with another variety. In the field the initial stand is considered established after thinning when taking data on wilt resistance, ignoring plants that can die soon after emergence, which may be caused by *Rhizoctonia*, *Colletotrichum* or even *Pythium*.

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[3] Recent correspondence from Dr. M. N. Walker has this to say: ''Since absolute immunity is rare, it is possible that there may be degrees of resistance, that is, a quantitative resistance. This may be determined by the number of genes directly affecting resistance or to indirect effects arising from genes affecting general vigor of the plant or specific response to environment. During my experience in Leesburg when I cut many roots at the end of the season, it was observed that survival could not be the final criterion. That is, the condition of the plants that survived was important. Two strains showing the same numerical survival showed marked differences in the apparent injury as judged by the evidence of infection in the cut roots. The word 'tolerance' is a dangerous one, but it is conceivable that relative vigor of two strains might result in one being able to survive an attack that would kill or seriously injure the other. This also involves a time factor and during several years I observed the seeming recovery of poor plants that hung on until extreme temperatures inhibited the fungus. Such plants would regenerate roots in the surface soil after the deeper roots had rotted off completely''.

To answer questions as "Why do infected seedlings in either the field or greenhouse appear healthy just a few hours before sudden wilting and death?", or "Why do older plants in the field suddenly die, appearing as though cut off at the soil surface?", Porter (29) showed that the external conditions of the environment that determine the rate of transpiration from leaves and the rate of evaporation from atmometer cups appear to influence the rate of wilting. Variation in the rate seems to depend on variations in the factors that influence transpiration, *viz.*, combinations of increased light intensity, abrupt or sustained rise in air temperature, low relative humidity, *etc.* The findings of Wilson (58) seem to indicate that a susceptible variety wilts because its plants cannot obtain enough water to compensate for that lost through transpiration, as the wilt fungus has congested the xylem tracheae and smaller vessels of seedlings with mycelium, and of plants 40–90 days old with gum-like materials and tyloses, in addition. Wilted seedlings can be induced to recover by placing them in a moist chamber where no further symptoms develop. Bennett (2) believes that wilt-resistance is a measure not of the failure of the fungus to enter a melon plant via the root tips and ruptures formed by newly emerged lateral roots (58), but of the inability of the fungus to develop sufficiently to produce the afore-mentioned plugging of the xylem tracheae. Older resistant plants withstand attacks of the wilt pathogen that are fatal to seedlings, apparently because a defense mechanism has had time to develop. Just what this defense mechanism is, Wilson (58) does not elaborate. Possibly the greater root-system of the older plant is involved.

Seed Production Of Wilt-Resistant Varieties. As indicated, wilt-resistant varieties are not immune; at best they are only 70 to 80 percent resistant. If growers attempt to produce seed on wilt-free soil or on infested soil on which the production of wilt is not certain, as is said to occur in the heavy soils of west Florida and Georgia, some plants of low resistance will mature a seed crop and also will cross with plants ordinarily resistant. Because resistance is inherited as a recessive character, any seed from these susceptible plants, or any seed from resistant plants that result from fertilization by pollen from the susceptible plants, will produce susceptible progenies in the next crop. Thus growers will receive the impression that resistance is not fixed and that the resistant variety is "running out" or "going back". Seed producers should locate infested soil, on which wilt is expressed, for reproduction of wilt-resistant varieties.

Anthracnose. Anthracnose, caused by the fungus *Colletotrichum lagenarium*

(Pass.) Ell. and Hals, is the worst disease of watermelons in the United States and is found almost everywhere that melons are grown, with the possible exception of California, and its seriousness can be realized from the figures of 20 to 30 per-cent loss reported from some States. It is especially serious and destructive in the southern States; in Florida it causes more loss than all other diseases of watermelon combined, and seldom a season passes without it's being a controlling factor in production. Anthracnose can be controlled by timely applications of fungicide, either by spraying or by dusting, using the old standards, Bordeaux mixture or copper-lime dust, but materials such as Dithane, Tri-basic Copper, Zerlate, Fermate, *etc.* do a better job. The correct time to apply a fungicide still remains to be worked out, and growers could save money by the initiation and development of an anthracnose-forecasting service to give accurate information on when to apply the necessary fungicide. Downy mildew could be included in this forecasting service.

Investigators have been considering the possibility of producing anthracnose-resistant watermelons since 1931 when Layton and Wilson (14) reported that Iowa Belle seemed to show less anthracnose injury in the greenhouse and field than Iowa King or Pride of Muscatine; Sherbakoff (38) recently has found that Iowa Belle, Iowa King and Pride of Muscatine are more susceptible to anthracnose in Tennessee than Stone Mountain. Later, Porter and Melhus (30) mention that Kafir and White seeded citrons possess some resistance, suggesting that this might be inbred with watermelon. In 1937 Layton (15) published that Red Seeded, Kansas Stock and Large Striped citrons were more anthracnose-susceptible than Kleckley Sweet, while the Colorado Preserving, Preserving and Green Seeded citrons were resistant. In addition, five varieties of African watermelon, two inedible and three edible, obtained from the Reverend Rush F. Wagner, Old Umtali Mission, Umtali, South Africa, possessed the "R+" type of resistance wherein infection is limited to small lesions resembling mechanical wounds accompanied by little or no injury, which Layton considered to be the only plant reaction usable for the development of resistant varieties. No similar reaction was found in the wilt-resistant selections out of Kleckley Sweet and Conqueror in the melon collection at Ames. The African melons were wilt-susceptible, but their seed and leaf characters were similar to those of commercial varieties. ✓The three edible strains, Africa 8, Africa 9 and Africa 13, were crossed to the wilt-resistant Iowa Belle and Iowa King, and by greenhouse inoculation with anthracnose the F_1 were found to be resistant, that is, resistance was dominant over susceptibility, and segregation in the F_2 and in the F_1 backcross suggested that a single factor pair for resistance or susceptibility was involved.✓ Layton used the lesions produced on the hypocotyl of young melon seedlings as his index of susceptibility or resistance, and showed further that leaf infection did not take place if the temperature was 15° C. or lower, while above 18° C. the infection was severe. Plants inoculated and held at the lower temperatures developed lesions later on the hypocotyl at ground level. Segregating F_2 plants were grown in the greenhouse, and those individuals resistant to anthracnose were transplanted to Fusarium wilt-infested soil. Surviving plants were then crossed on the wilt-resistant Klondike, Stone Mountain and Improved Kleckley Sweet No. 6 to improve the quality. In 1947 the Iowa station released their variety Black Kleckley, a cylindrical melon with very dark, almost black rind, and white to light tan seeds, resistant to anthracnose and Fusarium wilt. Unfortunately the variety was released while still segregating for seed color, and seed lots received at Leesburg showed a low percentage of black seeds. In Florida in 1947 the melon was late to mature, later than Blacklee, of good quality and showed a fair degree of resistance to anthracnose; its wilt resistance was not tested. The Black Kleckley is too small, 14–18 pounds, to serve as a shipping melon for Florida or Georgia.

In 1936 Layton sent four of his anthracnose-resistant melons with African ancestry to Walker at Leesburg, who grew the strains on wilt-infested soil. By 1941 there were a number of strains showing high resistance to wilt, differing in such physical characters as shape and size of melon, but all possessing light tan colored seed. Their quality was only fair, but they were anthracnose-resistant. In 1942 six crosses were made at Leesburg to combine this resistance with the wilt resistance and high quality of the Blacklee and other unnamed melons of this type, and with an unnamed wilt-resistant and high quality but undesirably small melon of the Cannon Ball type. The F_1 received preliminary testing for anthracnose resistance in the greenhouse in the late summer and fall of 1942, and findings were rather unexpected for plants seemed to be susceptible to the disease[4]. In 1943 and 1944 there was no plant pathologist at the Leesburg laboratory, and the progenies of the six crosses were studied in the field on Fusarium-wilt-infested land and purity of the lines maintained by selfing, but they received no further greenhouse testing for anthracnose resistance until after the 1945 growing season when the writer inoculated strains that had been selected, 41 in number. No resistance was found. The parental stocks carrying the anthracnose resistance also were tested and found to continue to possess the resistance described as "R+" by Layton (15). At that time it was considered strange that disease resistance was lacking, and this lack was attributed to the type of selections made in the field in 1943 and 1944 when quality had been emphasized while resistance was neglected. Since only one of the 41 lines has proved to be as early as the Blacklee, the others have been discarded.

The crosses made in 1942 to combine anthracnose resistance and the high quality of the Blacklee were repeated in 1946, and, in addition, several lines resistant to anthracnose and Fusarium wilt, received from the U. S. Regional Vegetable Laboratory, S. C., were employed as parents. The F_1 were grown in the field in the summer and early fall at Leesburg, on land treated with D-D mixture (20) to eradicate the root-knot nematode, *Heterodera marioni* (Cornu) Goodey. All plants showed susceptibility to anthracnose, which was contrary to the aforementioned report (15) that resistance was inherited as a dominant character. F_2 seed was planted in the field in 1947 and anthracnose was abundant; little resistance appeared, and inoculation in the greenhouse (August and September, 1947) showed not only that all lines were highly susceptible to anthracnose, but also that all parental material, formerly resistant, was now susceptible. Further tests, which will be reported in detail elsewhere, indicate the existence of more than a single physiological form of *Colletotrichum lagenarium.*

Dolan (7) studied a melon variety, the McCrea, referred to as "anthracnose resistant", which he used as parental material in inheritance studies on two melon anthracnose diseases caused by *Colletotrichum lagenarium* and *Marssonina melonis* n. sp., respectively. The McCrea was resistant to *Colletotrichum* but susceptible to *Marssonina,* and all plants of the segregating backcross and F_2 progenies had medium-to-severe infection with *Colletotrichum.* Most of the plants in each progeny were severely affected, and no definite resistance ratios were discernible. If resistance were dominant, as Layton (15) believed, these results are not easy to understand.

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[4] Verbal statement to the writer by Dr. M. N. Walker, December 1947.

Mosaic. Porter and Melhus (30) found that edible watermelon varieties are highly resistant, if not immune, to mosaic, but that the red seeded citron is susceptible. They crossed the inedible Kafir, White Seeded, Majorta, Mammoth White, Stock and Preserving Citron with five watermelon varieties and found that the F_1 were highly susceptible to the disease. When White Seeded and Kafir were used as parents the F_2 were less susceptible than when the others were the parents. Walker (47) recorded the first natural occurrence of mosaic.

Root Galls. Walker (50) found galls on the roots of citron plants and also on the F_1 of crosses of watermelon on citron. No causal agent was associated with the enlargements, and their nature is imperfectly understood.

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Chemurgic Utilization of Wood.

Wood consists of about 80% cellulose and 20% lignin, and the various processes employed in the conversion of it into a variety of products may be summarized as follows:

Paper Pulp: subjection of wood to the action of chemicals, such as sulfite or soda liquor, that react with and dissolve the lignin but have no effect on the cellulose fibers, produces the fibrous pulp.

Sugar and Alcohol: chips, sawdust or shavings of almost any species of wood subjected to the action of steam at 150 to 200 pounds per square inch pressure while dilute sulfuric acid solution is percolated through the bed of finely divided wood for three to four hours results in the cellulose of the wood being converted into hexose and pentose sugars, principally glucose, or dextrose, the sugar normally present in corn syrup and honey. This process, sometimes called "wood saccharification", since it results in the formation of sugars, is essentially hydrolysis of cellulose under the catalytic influence of sulfuric acid. "The acid solution containing sugars produced by the action of water on the cellulose is continuously removed from the digester. At the end of the reaction the digester contains the lignin residue from the wood, which is washed free of sugars with water. These washings are added to the sugar solution removed during the digestion, and this solution is then treated to neutralize the acid, after which it is fermented to produce alcohol.

"In processing a ton of wood in this manner about 1,000 pounds of sugars and 600 pounds of lignin will be obtained. The sugars can be converted by fermentation into about 50 gallons of alcohol and 375 pounds of yeast fodder. The latter contains 55 to 60 per cent protein that can be used as the sole source of protein in animal feeds. The ethyl alcohol produced in this manner is the same that is obtained from fermentation of grain or molasses".

Lignin. "The lignin residue from the hydrolysis process is compounded with various synthetic resins to produce moulding compounds from which plastic articles . . . are made. Fillers, such as wood flour, have been employed for this purpose, but by using the lignin residue from the hydrolysis process, the amount of synthetic resin (which is the more expensive ingredient of the moulding compound) can be materially reduced because the lignin filler itself acts as a resin extender". Such lignin plastics are suitable for battery boxes and other acid-containing articles. Because the lignin thus used "is a by-product from the production of the main product, alcohol, its price can be much lower than that of many of the other plastics manufactured at the present time".

"Plastics are also made from the lignin extracted from wood in the pulping process", and "some of the other uses to which lignin from pulping process has been put are: a) production of water-resistant adhesives for bonding plywood veneer, by reacting the lignin with amines or phenols; b) as corrosion inhibitors; c) as a flotation agent; and d) in production of ion exchange resins for water softening".

Improved or Transmuted Wood. By cutting wood into "veneer, and reassembling the thin sheets so that in every other layer the grain is at right angles to the direction that it is in the layers adjacent to it, and sealing the sheets to one another by applying glue between the surfaces, a panel is formed which does not shrink and swell like ordinary wood as humidity varies. The tendency of a layer to swell in width is restricted by the adjacent layers whose grain runs in the opposite direction. Such a construction has come to be known as plywood".

The original non-water-resistant glues used in making plywood have been replaced by water-resistant synthetic resins, the most widely used of which is phenolformaldehyde, or phenolic resin. "This resin is made by reacting phenol (carbolic acid) with formaldehyde (embalming fluid). To produce this resin the two ingredients are mixed in the desired proportion, a small amount of ammonia or sulphuric acid is added to catalyze or initiate the reaction, and the mixture heated. As heating is continued the reaction forms a thick, syrupy, amber colored phenolic resin. If this resin is heated for a time at about 300 degrees F it sets up into the hard, insoluble resin or plastic known as Bakelite.

"In making up plywood with phenolic resin the syrupy liquid just described is either spread on the surface of the plies with a glue spreader or strips of tissue impregnated with the syrupy resin are laid between the plies and the assembly placed between the platens of a hydraulic press at about 300 degrees F. and a pressure of 100 to 200 pounds per square inch applied. The pressure causes some of the resin to flow from the glue line into the wood to a depth sufficient to give a very strong bond when the heat has set it up into the hard product Bakelite; in fact the finished glue line is stronger than the wood itself".

"Synthetic resin bonded plywood was extensively used in the recent war for the production of aircraft, boats, and other military equipment as well as in buildings such as aircraft hangars and warehouses. By laminating and bonding with synthetic resins, immense integral beams of complicated design can be built up from relatively small pieces of wood. Wherever this resin bonded plywood has been used with proper regard to its limitations its performance has been excellent".

But water-proof glue lines do not mean water-proof panels, for, while the alternate cross-grain construction of such panels restricts shrinkage and swelling, changes in moisture content develop such tremendous stresses in the sheets of wood that the panels break down, not at the glue lines but in the wood itself. This has been overcome by impregnating the sheets of veneer with the resin—not merely applying the resin as a coating between the plies—and then converting the sheets into a hard plastic by heating. Wood built up of such impregnated sheets is known as "Impreg".

"Subsequently it was found that wood completely penetrated by the resin could be compressed to as little as one-third of its original thickness and when the resin had set, the panels could be removed from the presses without losing their highly densified condition, even when placed in boiling water. . . . The resin impregnated, laminated wood material that has been made super-hard by compressing it permanently to less than its natural thickness is called "Compreg". It will take up less than five percent water even when boiled in it".

"By means of resin impregnation and densification even inferior grades of wood can be made to surpass any of the highest grades of natural woods in strength and other properties. One field in which resin impregnation is used to impart special properties to wood is that of the textile industry. Heretofore these special properties have been obtained by selecting certain species of wood that through experience had been found to possess them. For example the bobbins used in the textile industry have largely been made of dogwood or hard maple, but because of the slow rate of growth of these species the available supplies are being rapidly depleted. By use of resin impregnation techniques it has been found possible to impart the desired properties to other species of wood whose growth rate is sufficiently rapid to assure a continuing supply".

"So far Impreg and Compreg have found use in war materials in such applications as spars, aircraft carrier decking, antennae masts, panels, bomb bay doors, expendable wing tanks, pontoons, propellers, and instrument panels in aircraft, and special applications for decking and paneling in boats. Peace-time uses include such items as mar-resistant and waterproof table tops, high grade furniture, spindles and bobbins for textile plants, electrical panels, and handles". (M. S. Hudson, *Chemurgic Digest 7 (8): 7. 1948*).

Hyoscine and Hyoscyamine. "One plant drug which was in short supply in all Allied countries during the recent war was the alkaloid hyoscine. This drug, which in larger doses is beloved by fiction writers as an obscure killing agent, was previously mainly used in association with morphine at childbirth and as an hypnotic agent in certain mental disorders. As the war progressed the demand for hyoscine rose to unprecedented levels as it was found to be of great value in the treatment of "bomb shock" and other war neuroses. Extensive experiments made in connection with the problem of motion sickness in seaborne troops revealed that hyoscine was the best drug available for alleviating the condition, and it was used freely from the Normandy invasion onwards.

"The small pre-war demand for hyoscine was easily met by reclaiming the alkaloid from the mother liquors after hyoscyamine (the chemical source of atropine) was extracted from the leaves of the belladonna plant *(Atropa Belladonna)*, or directly from other species of the Solanaceae, in *Datura* or *Hyoscyamus*, in which it occurred in small amounts. However, practically all the raw plant material had come from the European continent, and this, combined with the increased demand, resulted in an acute supply problem.

"It had long been known that the leaves of a tree of the potato family (Solanaceae), indigenous to Australia and New Caledonia, popularly known as "corkwood" on account of its spongy cork-like bark, and scientifically as *Duboisia myoporoides*, contained a complex of alkaloids with physiological effects similar to those of atropine. As a result of the wartime emergency, interest in the species, as well as in that of a second member of the genus, *D. Leichhardtii*, was re-awakened. The Australian Council for Scientific and Industrial Research, working in co-operation with the Universities of Sydney and Melbourne, began an investigation and discovered that not only did hyoscine occur in the leaves of certain types of both species, but that it did so in concentrations four or five times as great as had been found in any other plant. As a result of intensive laboratory and field tests a commercial firm was soon producing hyoscine in adequate quantities and at a lower price than had previously been thought possible. During the war emergency, more than 7,000 ounces of the drug were produced in Australia from this new source. This is said to exceed the total amount which had previously been produced in the world.

"There are only three species of the genus *Duboisia*, none of which occurs beyond Oceania. The third species, *D. Hopwoodii*, is a desert tree confined to the arid interior of the Australian continent which, strangely enough, does not carry the hyoscine-hyosciamine group of alkaloids, but is rich in nicotine and nor-nicotine. *D. myoporoides* is a subtropical species having a scattered distribution along the eastern coast of Australia, whilst *D. Leichhardtii* is confined to a relatively small section of the southeastern highlands of Queensland. The latter species in particular is not plentiful and the wartime demand made such heavy inroads upon the natural stands that at one stage it was feared that it might become extinct. The characteristic of vegetative regeneration after cutting back, which is common to both species, has undoubtedly been one of the principal factors in their preservation. Neither species is strongly competitive and both are readily crowded out by other trees. They have a very scattered distribution and are generally found as isolated trees or small groups in forest clearings or along river banks. In certain areas, plants of *Duboisia* are among the first to establish themselves after forest fires, but they ultimately give way to the more permanent secondary flora.

"The species have hitherto only been known in the wild state but successful methods of cultivation have now been devised and there seems no reason why the species should not take their place alongside the regularly cultivated drug plants such as digitalis and belladonna. Although their natural habitat is subtropical, they have shown a wide range of climatic adaptation under experimental conditions and have been found to survive quite severe frosts. Under good conditions seedling trees have been observed to increase in height at the rate of 1 inch per day for periods as long as a month.

"The method of cultivation adopted is based on the maintenance of the plants as bushes rather than trees. They appear to maintain their perennial nature when trimmed regularly, and yields on the order of one ton of dry leaf per acre per year have been obtained. Leaf grown under such conditions contains at least as great a quantity of alkaloids as that collected from wild stands.

"Selection and testing of different types found within the species has gone forward concurrently with the cultivation trials. Although the genetic-environmental relationships of the alkaloid complex are somewhat involved, it has been possible to isolate types which yield hyoscyamine under any environmental conditions and others which yield hyoscine in most circumstances. In many cases the alkaloids are present together, the proportion of each depending on the environmental conditions and the genetic nature of the material.

"The rapid growth of *Duboisia* and its adaptability to cultivation, combined with a very high percentage of alkaloid in the leaves, should insure its becoming the principal world source of hyoscine, and possibly also of hyoscyamine. Seed has been sent from Australia to other countries, including the United States of America, and it is expected that the species will ultimately be cultivated successfully wherever conditions of soil and climate are suitable throughout the world". (K. L. Hills, *Jour. N. Y. Bot. Gard.* 49: 185. 1948).

Cocona. An almost unknown but highly promising edible fruit of the upper Amazon is the cocona, *Solanum hyporhodium*. Credit for its introduction from the wilderness to the garden is due staff members of the Tingo Maria Experiment Station of Peru where attempts are being made to improve it through selection and hybridization with several closely related species, especially *S. quitoense*, *S. hirsutissimum* and *S. hirtum*.

"Cocona plants grow to a height of four or five feet, having a coarse sprawling shrublike growth with very large leaves. They are completely spineless and have prospered in full sunlight at Turrialba, Costa Rica.

"The ovoid fruits, which are suggestive of large red or yellow apples, are held in compact clusters close to the trunk and branches. The plants are heavily productive, ofttimes being loaded down with from 40 to 60, or more, pounds of fruit. About seven months are required from planting to first harvest. Ripening may then continue for several months.

"Upon reaching maturity, cocona fruits turn from the earlier bright-yellow to deep-red or burnt-orange color and are then most attractive. At this stage the peachlike fuzz which is typical of this tribe of edible large-berried fruits of the genus *Solanum* is easily brushed off, leaving a clear and blemish-free skin.

"The flesh and inner pulp are of a pale-cream color throughout, a fact which readily distinguishes this fruit from its two nearest relatives, the naranjilla and lulita, the pulp of which is a translucent green color.

"Although the flavor of uncooked coconas is agreeable, the pulp is distinctly acid, and they are not recommended for eating out of hand. When peeled as an apple and used entire for making preserves, pies and sauces, the product might be compared with that of an apricot, pineapple or gooseberry. Cocona marmalade and preserves are a rich transparent orange in color, and their tart and spicy flavor is both delicious and distinctive. One can safely say that there are few fruits available to the warm humid sections that can equal or surpass the better forms of this fruit for such culinary uses".

"*Solanum quitoense* is the plant known and cultivated as 'naranjilla' and 'lulu' in the more northern Andean regions of South America. In the highlands of Ecuador and southern Colombia the naranjilla is highly prized as a juice fruit and constitutes an important economic commodity. It is found wild from Costa Rica to Peru.

"Unfortunately, this species has seldom prospered in other regions, owing largely to sensitivity to environment. At Turrialba, Costa Rica, the naranjilla must be grown in half shade and has not relished high temperatures or dry soils. The ripe fruits are aromatic and acid though low in sugar. Keeping or shipping qualities are only fair.

"The lulita, of the species botanically known as *S. hirsutissimum*, is occasionally found in the warmer and dryer parts of Costa Rica and Panama and as far south as Peru. It is little known either horticulturally or botanically. At Turrialba it prospers in full sunlight and has withstood considerable drought. The fuzzy or hairy fruits are about the size and shape of a hen's egg and when ripe show a rich orange color. The plants are extremely spiny.

"With full maturity, fruit of the better lulita selections is quite agreeable, being aromatic, juicy, and tart with a flavor suggestive of plums. With certain refinements, this species could become truly desirable for eating out of hand. In general, the fruits indicate a higher sugar content than do either the cocona or the naranjilla, although they are typically quite seedy. The better strains of this species might contribute admirably to a breeding project in way of fruit and cultural assets.

"Preliminary efforts to hybridize these species have resulted in little encouragement to date. Fruit setting from pollinated flowers has not been too difficult to accomplish, although the seeds obtained generally have been poorly developed and in all cases have failed to germinate. The mere fact, however, that in a few instances plump seeds were formed affords some hope that ultimate success may be possible.

"In any event, a safe assumption is that even in its present unimproved state the cocona is a permanent acquisition as a valuable horticultural plant. Anyone who has seen it, or has eaten the appetizing culinary products made of it, will testify to that. The possibilities of its culture in temperate climates must yet be determined". (*J. L. Fennell, Foreign Agriculture* 12: 181. 1948).

Cedarwood Oil. *Juniperus virginiana*, naturally distributed east of the Rocky Mountains from Canada to Florida, has for many years been the chief source of cedarwood oil for the aromatic trade. For about 18 years, however, Texas, or Mexican, cedar (*Juniperus mexicana*) has also been a source of cedarwood oil which has appeared on the market intermittently in a crude state without any refining. This species, a usually crooked and irregular tree up to 20 feet in height, inhabits the rough limestone hills of central and west Texas, originally covering about seven million acres. Clearance work to increase grass production has reduced the area with trees to about three million acres. The few limbs of this species "that are straight have been used to some extent for fences and house blocks, but these are the only uses that have ever been found for this cedar with the exception of oil. These trees are too crooked and irregular for sawing and the wood checks after it has been exposed to the atmosphere".

The only cedarwood distillation plant in the *Juniperus mexicana* area, on the Guadalupe River about three miles north of New Braunfels, Texas, has been bought by the Southwest Cedar Oil Company and is now grinding about 50,000 pounds of cedarwood daily for the production of oil. The company has also established a laboratory to explore all possible uses of the oil.

"For oil distillation the wood is usually cut by Mexicans on a contract basis by the cord and is stacked in the cut-over area to dry. When dry, the wood grinds and distills better than when green. It is usually seasoned for 90 days, but is not harmed if left outdoors for a year or two.

"When ready to use, the wood is dumped into a conveyor which carries it to the wood hog or chipper and thence into the hammer mill which reduces the size of the chips to 6 mesh. The chips are collected in a cyclone. A conveyor then dumps them into the top of a still. The stills are 7 x 10 feet and will hold about 5000 pounds of grindings.

"Steam is fed into the bottom of the still and is distributed so as to come up uniformly through the mass of wood. After the distillation is finished, the wood is dumped into a triangular hopper at the bottom and is carried out by conveyor, either to the boiler firebox or to the wood stack outside. The boiler uses about 50 percent of the wood residue.

"The steam picks up the volatile oil and carries it to the oil house where it is separated from the water in condensation. The oil at this stage is crude and dark red. It is shipped to the fractionating plant in San Antonio.

"Plans for distillation of the leaves have not been put into effect as yet. The leaves carry about 1¼ percent crude oil, of which about 40 percent is gum camphor and the other 60 percent a very pungent leaf oil. The camphor has been tested and apparently is chemically identical with Formosa camphor but none of the leaf oil or camphor has ever been put on the market. Laboratory work has been carried to a point where all information has been worked out for a pilot plant for the separation of the camphor from the leaf oil and it is planned to get this in production within the next few months.

"After the crude oil reaches the fractionating plant at San Antonio, the oil is run into a high vacuum still for first processing. Although laboratory tests have broken down the crude oil into 27 separate fractions, this quantity would be excessive for commercial production at the present time. Accordingly, only four separations are made in the crude: the white oil, pseudo cedrol, crystalline cedrol, and cedarwood tar. These products form the basis for the other products that are made from the oil by blending, redistilling, cracking, synthesizing, or recrystallization, depending on the product that is desired. There are 16 different oils and other products produced from these four basic fractions, and each of the oils and other products has its own characteristics.

"Cedrol content of the crude oil is very high and the extreme stability of the cedrol and the pseudo cedrol offers possibilities for fields where an alcohol of this type would prove advantageous, some of which have been determined. Research is being continued on the cedrols as well as the hydro carbons.

"Most of the oils and other products thus far developed have been for the aromatic field. This group includes eleven oils, pseudo cedrol, crystalline cedrol, recrystallized cedrol, cedarwood tar oil and cedarwood tar.

"These products have proved to be of value for aromatic perfumes, soaps, a fungicide for leather, activator in insecticides, carbon remover for gas engines, furniture and floor polishes, moth proof clothing bags and cabinents, lubricating greases, printing inks, carbon paper and typewriter ribbons".

Other uses and potential uses of Mexican cedarwood oil include: *a*) fungus inhibitor in chrome tanned leather, *b*) leather preservative, *c*) moth-proofing spray, *d*) flotation agent. And the ground wood, after being steam distilled to extract the oil, is valuable as a conditioner of alkaline soils. For this purpose the ground wood has been impregnated with minor elements. (C. Pool, *Chemurgic Digest 7(7): 7. 1948*).

Wormwood. "Time was when the wormwood plant (*Artemisia Absinthium*) was used chiefly for the preparation of absinthe—a green, bitter, aromatic liqueur that came to be known as one of the most notorious of all alcoholic beverages. Today, however, the only known use of wormwood in the United States is for its yield of an oil that is one of the principal ingredients of certain external liniments to warm the muscles instead of assuaging the stomach.

"Practically all of this chemurgic crop that is produced in this country is grown in St. Joseph, Cass, and Allegan counties in Michigan, and in St. Joseph county in Indiana. Much of the crop is purchased by a single company, W. F. Young, Inc., of Springfield, Mass., manufacturers of 'Absorbine' preparations.

"In an unusual arrangement for production and purchase of a farm crop, the Young Company contracts for its purchases several years in advance. The contracts guarantee the farmers who sign a fixed price for all the oil they can produce on a specified acreage.

"Growers usually get a crop that yields from 15 to 20 pounds of oil per acre, and some have gone as high as 35 pounds. The usual gross income at present prices is from $90 to $120 per acre, but unless chemists discover additional uses, the prospects for expanded acreage are relatively light.

"Wormwood is a perennial that usually lasts for seven to 10 years from a single planting. It is originally grown in beds, and is transplanted with the help of mechanical setters.

"The oil of wormwood is obtained by steam distillation. On reaching maturity, the plants are cut and hauled to a still. There they are tightly packed in tubs or vats, and cooked for one to two hours in live steam.

"The oil content is carried into the steam overflow from the vats, thence through a condenser where the oil is separated from the water. The residue is usually spread over the freshly cut fields as a mulch to keep down weed growth.

"The Young Company estimates from 2300 to 2900 acres of wormwood is grown in this country. One of the largest producers is T. C. Carter & Son, Vandalia, Mich." (*Anon. Chemurgic Digest 8(1): 11. 1949*).

Cottonseed. At present 4½ million tons of cottonseed are produced annually in the United States, over 40% of the world's production. Cottonseed ranks fourth in value among the nation's crops, and its value combined with that of staple cotton, places cotton very close to corn, the leader.

Cottonseed is the principal source of protein feed for the South, obtained as a byproduct of oil extraction, and considerable research in its processing and byproduct utilization is being conducted at the various State Colleges of the South under sponsorship of the Texas Cotton Research Committee, and at the Regional Laboratories of the U. S. Department of Agriculture.

"Corn is now processed to obtain pure starch, dextrin, sugar, syrup, zein, oil and inositol. Cottonseed contains an even greater wealth of chemicals which are not as yet separated in pure form to obtain their greatest value.

"At present cottonseed is processed essentially by the hydraulic press method. The short fibers left on the seed by the cotton gin are removed by linter machines, similar to gins, which pull the fibers off with rotating saws. Hulls are next removed by disc mills or bar hullers and separated from the meats by screens and air separation. The meats are rolled into flakes, cooked for about an hour at 240° F., and the oil then squeezed out by hydraulic presses. In some instances the oil is squeezed out by screw expellers which force the meats at high pressure through slotted tubes.

"Cottonseed linters are sold as raw material for rayon, gun cotton, and for upholstering. The hulls are used mainly for livestock roughage although their consumption for the manufacture of furfural has increased since the discovery of a method for converting furfural to nylon.

"Cottonseed is the standard source of protein feed for the southern farmers. It is of excellent quality and highly palatable to animals. It is sold for direct use or blended into mixed feed. The cottonseed oil is usually sold in the crude form to the vegetable oil refiner who makes it into shortening and margarine.

"The most important development in cottonseed has been the use of solvent extraction methods. Solvent extraction has proved its value in the soybean industry where the capacity of solvent extraction plants has tremendously increased. However, its use in processing cottonseed in this country is so new that its success has not yet been established.

"The first solvent plant for cottonseed in this country was completed at Wilson, Arkansas, less than a year ago. Since then plants have been constructed for cottonseed extraction at Helena, Ark., Memphis, Tenn. and Abilene, Tex. As yet, practically no technical information on the operation of these plants is available".

The standard solvent used is a petroleum fraction containing essentially n-hexane. The oil is recovered by evaporation of the solvent which in turn is condensed and reused. Other solvents, such as alcohols and chlorinated hydrocarbons, are being considered. Isopropanol, the ordinary rubbing alcohol of the drug store and easily produced from petroleum cracked gases also appears to be a suitable solvent, for, in addition to removing the oil it also dissolves gossypol and related substances which when left in the meal are toxic to certain animals. Gossypol is rendered inactive by cooking the meats before pressing, but cooking has been shown to be detrimental to the protein in the meal.

Oil, fatty acids and sugars can be separated from the isopropanol extract. The sugar is non-sweet, normally indigestible raffinose which can by hydrolized into simpler, sweet, digestible sugar. The oil "contains appreciable quantities of three other valuable substances: the phosphatides, tocopherols and sterols. These substances are now wholly or partially wasted in processing. Lecithin is the commonly known phosphatide. It is now produced commercially as a by-product in the soybean extraction process, and has a wide variety of uses. The tocopherols are known as Vitamin E and are prepared by molecular distillation of the oils. In addition to their vitamin uses they are valuable antioxidants for preventing rancidity in fats. Cottonseed is one of the richest of the common oils in tocopherol content.

"The sterols are chemically inert and do not contribute to any important property of the oil. However, they constitute starting materials for synthesis of sex hormones and are used for preparation of Vitamin D.

"A ton of cottonseed will contain 6.5 lbs. of lecithin, 5.4 lbs. of sterols, and 0.4 lbs. of tocopherols. The latter two substances have a very high commercial value in purified form. Alpha-tocopherol is quoted at $340 per lb. From 10 to 15 lbs. of gossypol are contained in a ton of cottonseed. As yet gossypol has no commercial value; however, if it were isolated in pure form, uses would surely be found. It is an excellent antioxidizing agent.

"The lecithin, vitamin E sterols, and gossypol are all obtained in concentrated fractions by the isopropanol extraction process for cottonseed oil. Purification of these substances should not be difficult, and they can then be produced as new marketable products from cottonseed. In addition, the higher grade meal, freed of its impurities, will be a source of flour for human consumption and commercial protein for fiber and plastic manufacture". (W. D. Harris, *Chemurgic Digest 7(11): 9. 1948*).

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Semi-Popular Articles

MILKWEED—A WAR STRATEGIC MATERIAL AND A POTENTIAL INDUSTRIAL CROP FOR SUB-MARGINAL LANDS IN THE UNITED STATES. *Boris Berkman* 223

MANICOBA AND MANGABEIRA RUBBERS. *Robert W. Schery* 240

WORLD PRODUCTION AND CONSUMPTION OF MILLET AND SORGHUM. *Elna Anderson and John H. Martin* 265

PLANT GROWTH-REGULATORS. *R. L. Weintraub and A. G. Norman* 289

Technical Literature Review

FOREST-TREE GENETICS RESEARCH: *Populus* L. *Scott S. Pauley* 299

Utilization Abstracts

By the Editor

Page 239—Bamboo Paper Pulp. Bamboo Blowgun. *Page 288*—Cortisone from Yams. *Page 331*—Waxes and Fats from Sugarcane.

Corrections

On page 114 of the preceding issue of ECONOMIC BOTANY, *Yucca baccata* should read *Yucca elata*, and on page 127 the creosote bush (*Larrea divaricata*), not the greasewood bush (*Sarcobatus vermiculatus*), should be reported as the source of nordihydroguaiaretic acid.

See page 330 of this issue for another correction.

Milkweed—*A War Strategic Material and a Potential Industrial Crop for Sub-marginal Lands in the United States*

In 1943 the U. S. Federal Government erected a milkweed floss- and seed-extracting plant at Petoskey, Michigan, the only one of its kind in the world, and in one year this plant furnished to the armed forces two million pounds of milkweed floss that was used in lieu of kapok from Java in the manufacture of lifesaving equipment. Two million pounds of seed and tons of fibers were by-products as potential commercial sources of oil and cellulose, respectively.

BORIS BERKMAN
President, Milkweed Floss Corporation of America, Chicago, Illinois

Introduction

Theories of today may be the stepping stones to the facts of tomorrow, and alleged facts of today may be proven unsound theories in the light of future discoveries. As examples, one has only to recall that heavier-than-air craft, splitting of the atom, radio and television, all established facts of today, were unheard of 50 years ago, or were regarded at that time only as fantastic theories. On the other hand, rigid dogma of yesterday, which considered molds only as toxic and undesirable factors in decomposition, must, in the light of penicillin and other antibiotics, be discarded today as unsound and unscientific.

The history of the utilization of plants for the benefit of the human race is full of similar evidence that it takes a long time for new thoughts, though they embody definite improvements, to be accepted, especially if those thoughts contradict old established concepts of usefulness and desirability. The corn plant in North America, highly esteemed as a valuable food by the native Indians, was considered undesirable and had a hard time becoming accepted by the early white settlers of North America. Only 30 years ago the soybean was ridiculed in the United States, and the probability that it would ever become a major crop was negligible. At present it is one of our most important crops, the source of countless food and industrial products.

In the light of these historical precedents, the concept of the milkweed plant as a potentially valuable raw material for several industrial products, as implied in the title to this article, should not be discarded lightly. Use of the floss as an emergency strategic material during the recent war has already established the plant's potential value. This use and the possibilities of other industrial utilization are discussed in this article.

Utilization Prior to the Twentieth Century

The milkweed family, the Asclepiadaceae, contains a large number of fiber-producing herbaceous plants native to different portions of the world and varying from shrubby growths, a few feet in height, to the giant forms of India that attain ten feet or more. More than 20 species are native to the United States, probably the commonest and best known of which is *Asclepias syriaca* L. This species grows wild in Canada and over wide sections of the United States, and is as well known in portions of South America and of southern Europe. Among specimens of it in the old Glover Museum of the United States Department of Agriculture there are some fine examples from Brazil which were most carefully prepared, seeming to show that the value of the plant was recognized in that country. According to one of the old authorities: "an early knowledge of the fibre of silkweed caused the introduction into Europe, where it has fully become a cultivated plant, while in its own country but little is known of its true value" (9).

Among several other fiber-producing species of the Asclepiadaceae, and found chiefly in the Old World, is *Marsdenia tenacissima,* W & A, or Rejmahl Bowstring Creeper, the source of the jeete fiber of India. This twining shrub grows in the Rejmahl hills of that country, in dry and barren places, and the fibers of the bark are used by the mountaineers for making bowstrings. The fibers are reported to be not only beautiful but strong and durable. In Roxburg's test of twine (8) made from jeete, he found that in the dry and wet states it bore strains of 248 and 343 pounds, respectively, whereas comparable figures for hemp were only 158 and 190. The fiber has long been widely employed in its native land for making nets and is not liable to injury by being kept in water.

The prehistoric Indians of North America used the bast fibers of milkweed for textile purposes. *Asclepias syriaca* was the most widely employed, and clothing found in ancient burial places, 1,000 years old, were made from it. Whitford (47) attributes such use to the fibers of four species, *A. tuberosa* L., *A. pulchra* Ehrh., *A. incarnata* L., and *A. syriaca* L. Other Indian tribes of North America relied upon the milkweed plant for food and medicinal benefits. Buds of *Asclepias incarnata* L. were dried and stored for winter use by the Menominee Indians, or were made into soup with deer broth, or added to cornmeal mush. The leaves and young shoots of *A. speciosa* Torrey were boiled with meat by the Hopi Indians of Arizona; in Montana and California the flowers were eaten boiled or raw; and in Wisconsin, Minnesota, Montana and Wyoming the seeds were eaten raw and the buds consumed with meat or boiled with soup. In New Mexico *A. involucrata* Eng. was similarly used for food. The Chippewa Indians used the flowers of *A. syriaca* in a stewed form, and the Iroquois ate young green fruits, young sprouts and buds.

Kalm (20) says that the French in Canada used the tender spring shoots of milkweed, preparing them like asparagus, and that they also made a very palatable sugar from the flowers. Tremont (42) found the Sioux Indians of the upper Platte River eating young pods and boiling them with buffalo meat. Jeffery, referring to Canada (42), says: "What they call here the cotton tree is a plant which sprouts like asparagus to the height of about three feet and is crowned with several tufts of flowers; these are shaken early in the morning before the dew is off of them, when there falls from them, with the dew, a kind of honey, which is reduced to sugar by boiling".

Natives of Tanganyika use the bast fibers from the stalks of *A. semilunata* N.E.Br. for fishnets (6), and in the central part of India the bast fibers of *A. gigantea* L. have been employed by the natives for textile purposes. Gleditsch in Germany used the floss of milkweed for padding, and in 1754 he reported the results of experimental work with *Asclepias* to the Academy of Science in Berlin. LaRouviere in France produced cloth from the floss at about the same time (27), and in 1811 Baron Jacquin published a detailed description of the milkweed plant. Several ventures in the cultivation and possible utilization of *A. incarnata* and *A. syriaca* were made in Canada about the middle of the last century, along with similar work in Russia (21, 23).

Utilization in the Twentieth Century exclusive of the Floss

It soon became apparent to twentieth century investigators of the utilitarian qualities inherent in milkweed that utilizing the products of these plants in the primitive manner of a century ago precluded successively growing milkweed as a regular and economically profitable crop. Only by taking advantage of chemical and mechanical sciences could this crop be converted into products, such as floss, synthetic fibers, oil, wax, rubber and plastics, that would command profitable prices and could be utilized as raw material for important industrial enterprises. To that end there has been a revival of interest in the United States, Canada and Russia during recent years in the chemurgic possibilities of milkweed. This revival is attributable not only to the application of chemistry to the utilization of agricultural products in general, but also to improvements in the processing of milkweed floss, as will be described later in detail.

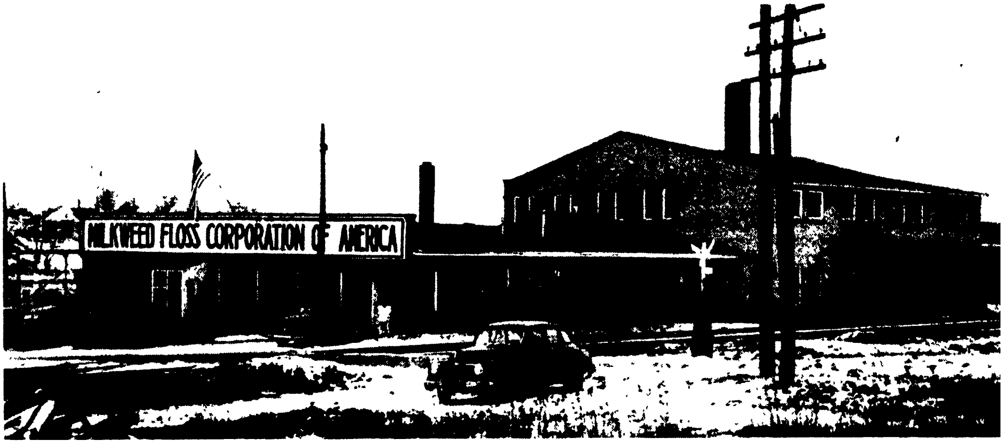


Fig. 1. The milkweed-processing plant of the Milkweed Floss Corporation of America, built by the U. S. Federal Government in Petoskey, Michigan, in 1943 at a cost of $225,000, to furnish milkweed floss to the armed forces during World War II for use by them principally in life preservers. It produced more than two million pounds of the floss for this purpose in the one year of its operation.

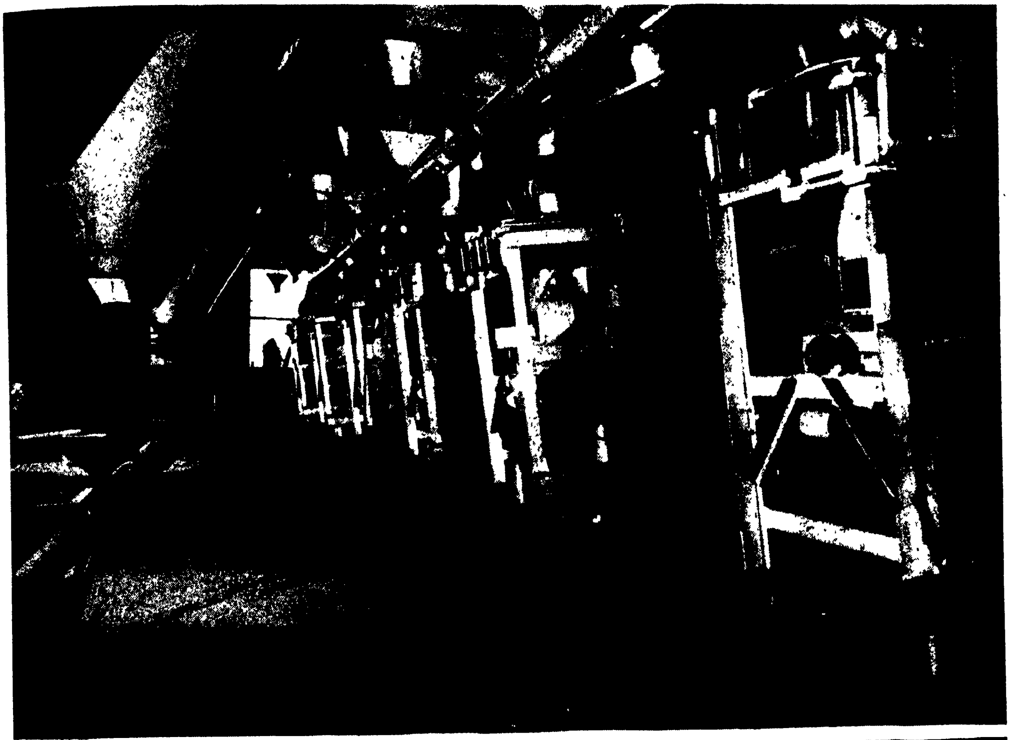
In Russia this revival of interest has been devoted to the extraction of oil and fat from the seeds, and of latex from the leaves and stalks (25, 30, 31). Stepanov (38), for instance, analyzed milkweed as an oil- and rubber-producing plant, and reported that "oil from the seeds of milkweed can be used *a*) for the manufacture of liquid soap, for which there is a large demand in the textile industry; *b*) for the production of siccatives; *c*) for the production of fats by hydrogenation. Our rubber industry should put an end to its persistent understimation of this plant as a source of rubber. Cultivation of this plant should yield thousands of tons of natural rubber, to be mixed with our synthetic rubber. Milkweed should occupy a proper place among our valuable technical plants". He mentions the possibility of utilizing the stems in the paper industry, but does not say anything about the floss.

In Canada we find the same trend of thought, especially during World War II when a great deal of work was done at the Central Experimental Farm in Ottawa on the propagation and cultivation of the plants, on germination of their seeds, *etc.* Some of the best cultivated fields of *Asclepias incarnata* and *A. syriaca* observed by the author have been in Ottawa. In 1943 over 500 acres of land in Peterborough County as well as at Ottawa were seeded by the farmers, subsidized by the Canadian government. A cooperative research program, involving various government departments and universities, on the extraction of resin rubber gum from the common milkweed has been under way in Canada since 1942. Based on a series of batch operations worked out in the laboratory, a pilot plant has been built in Ottawa that is capable of rapid extraction of substantial amounts of gum. The design includes provision for ultimate integration to continuous operation. A 15–85 milkweed gum CR.s mixture in a tire tread compound resulted in an improvement in tack, an increase in tear resistance, a drop in both tensile strength and modulus, an increase in elongation at overcure, a drop in resilience, an improvement in the heat embrittlement figure, and a considerable improvement in flex life (12, 14, 32, 46).

It is apparent from several writers (*e.g.*, 12, 13, 14, 46) that the rubber possibilities of *Asclepias* have been predominant in the minds of Canadian scientists, and that the same tendency has prevailed in the U. S. Department of Agriculture and among independent investigators (2, 7, 15, 17). Edison and Ford, among the latter, were interested primarily in latex, and avoided investigating any other utilitarian possibilities of milkweed. All these investigators have been confronted by one basic fact which is of prime importance in the usefulness of milkweed as a profitable rubber-producing source, namely, that the rubber content of milkweed is not sufficiently high to make the growing of it exclusively as a source of rubber a sound commercial venture. Other products, producing additional income, must be obtained before it can seriously be considered as an industrial crop. Among such other products is the floss attached to the seeds within the seed pods, but before the utilization of that floss could be developed it was very apparent that a mechanized method of separating the floss from the seeds and pods would have to be developed, for only then could the plants produce enough revenue to make their production and processing profitable.

Milkweed Floss as a Strategic Material of World War II

The incentive to develop such a method of mechanically isolating the floss from milkweed pods was provided by the exigencies of World War II. Previous to the seizure of the Dutch East Indies in 1942 by the Japanese, the world's foremost commercially important stuffing material for life preservers, life cushions and similar articles was kapok, imported by the United States in large quantities, chiefly from Java, the Philippine Islands and Ceylon. Kapok, like milkweed floss, is a seed fiber and is produced on the seeds within the large pods of the kapok, or silk cotton tree. This is a large, widespreading tree (*Ceiba pentandra* Gaert.) with enormous buttressed roots, native to the American tropics but now extensively planted in the tropics of both hemispheres. When the East Indian supply of kapok ceased there arose a



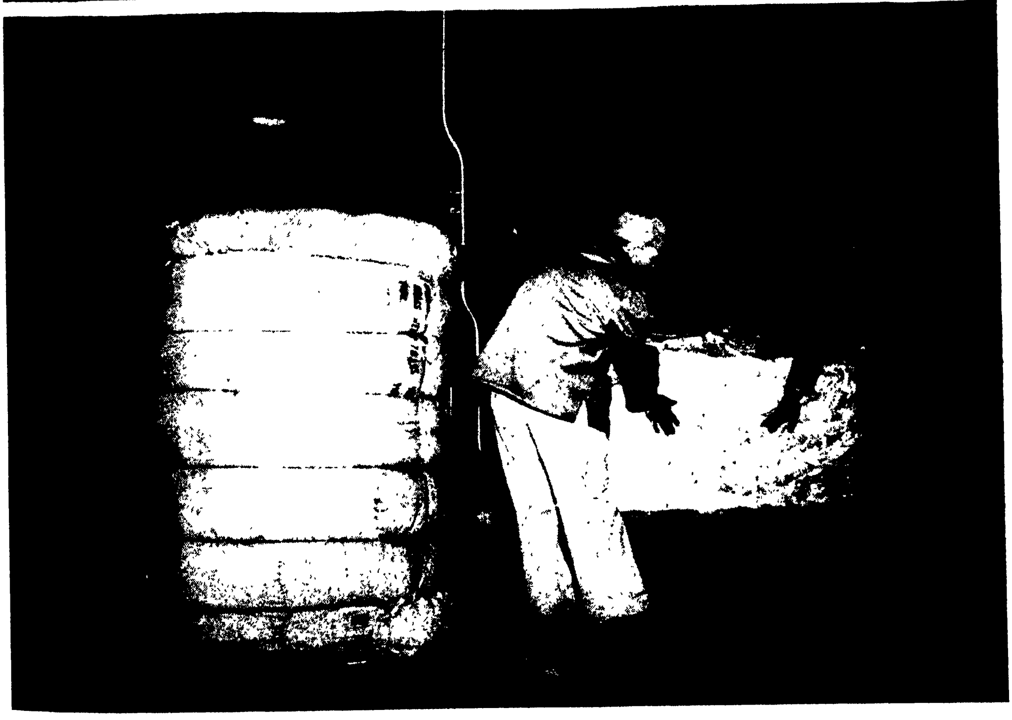


Fig. 2 (*Upper*). The "milkweed gin" which solved the problem of mechanically separating floss from seeds and thus tremendously accelerated the processing of these two plant products.

Fig. 3 (*Lower*). The baler which packed the floss into bales averaging 200 pounds in weight.

need for substitutes, as was true of so many other items of international trade, and the possibility of using milkweed floss in its place became apparent.

Inspired by this need, the author and his co-workers continued their efforts begun in 1938 to develop a satisfactory process for achieving the above mentioned aims. The result was a "milkweed gin" to accomplish them. In 1941 the author submitted to officials of the U. S. Navy a memorandum regarding the value of milkweed floss for life preservers and other life-saving equipment, and the next year he was invited to present his testimony before the Agricultural Committee of Congress. Tests conducted by the Navy proved that the floss is equal in performance for life-saving equipment to kapok imported from Java, and in 1942 the Federal Government appropriated over $200,000 to build a processing plant. The fund was administered by the Defense Plant Corporation, and the processing plant, the first of its kind in the world, was constructed in 1943 under the supervision of the author and Mr. L. J. Lyon, President and Vice-President, respectively, of the newly established Milkweed Floss Corporation of America. The plant was located in Petoskey, Michigan, in a region where the greatest concentration of wild milkweed in the United States is to be found. To furnish the plant with raw material, the Commodity Credit Corporation, as an agency of the Government, collected milkweed pods in 26 States with the cooperation of farm organizations, youth clubs, school children and other organized assistance. Over 2,500,000 bags were collected in the years of 1944–45, representing 25,000 000 pounds in green weight, or 10,000,000 pounds in dry weight. To transport this huge quantity of pods, 700 freight cars were used. About 2,000,000 pounds of floss were processed in the Petoskey plant in one single year, the floss representing about 20% of the gross weight of the pods, the seeds 36%, the podshells 44%. The floss was delivered to the armed forces during the war, to be used principally for the manufacture of life-preservers.

The pods were collected in wide-mesh onion bags, since they had to be air-dried in order to lose 60% of their water content before it was safe to stack them for transportation to the Petoskey plant. A huge specially built dryer, capable of removing excess moisture from a thousand bags of pods per hour, was installed in the Petoskey plant. Pods, after travelling on a conveyor through this dryer, were dumped on a second conveyor which brought them up to the second floor of the building where the contents of the bags were emptied into milkweed gins located on the first floor. The opening of the bags represented the only manual operation; the entire separation process was 100% mechanized. The milkweed gins and the attached air-separating units separated the pod content, allowing the floss to be carried by air to the huge collecting chambers; the seeds and pod shells were deposited on other conveyors which brought them to a separate collecting room. This air-separating system was operated so effectively that floss from pods not entirely ripe, or damaged by mold, was rejected. This prevented contamination of good floss by imperfect material, which was very important, because if floss gathered in the collection room was contaminated with mold, then baled, the outer layers of the bales would act as insulators and help spread the mold throughout the bales. Bales of floss imported from South America and other countries where hand-separation was used, sometimes contained large amounts of yellowish moldy material. The milkweed gin could also handle pods that had been only air-dried; but machine-drying, in addition to air-drying, made the gin more efficient. In addition to assuring greater uniformity in drying than might otherwise have been achieved, the drying and processing method developed at Petoskey eliminated handling of the fibers by hand and thus provided a degree of sanitation that was of importance in certain lines of use. And, finally, it made possible the handling of billions of fibers in a fraction of the time necessary in hand operation.

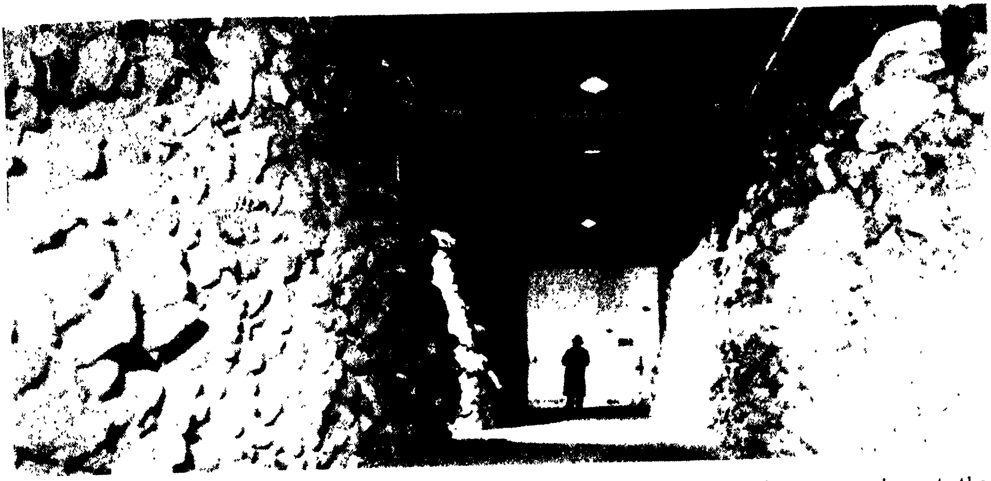


Fig. 4. Ten-pound bags of air-dried milkweed pods in storage before processing at the Petoskey plant.

Utilization of the Floss

Milkweed floss is the lightest known material. It is one-sixth as heavy as wool, and lighter than down or kapok. Besides being a perfect insulator, it provides buoyancy. Therefore, suits made with this material quilted into the lining serve three purposes: they are lightweight, warm and buoyant, and, in addition, the lining is vermin and bacteria-resistant. The BTU of the floss is less than 0.24, and one pound, ten ounces of the material will keep a 150-pound man floating in water more than 48 hours. It was because of these qualities that the floss was utilized by the naval forces of the United States in recent years. However, milkweed floss could not be used in clothing as an insulating material unless special machinery could be developed to distribute the floss in absolutely equal thickness between textile sheets, and then by quilting, to prevent the shifting of the floss. In the post-war period such equipment has been developed, and it is now possible, therefore, to utilize the floss as an excellent insulating material for clothing, especially for regions having very low temperatures. Recent tests conducted on a large scale established the fact that milkweed floss is an insulating material of outstanding merit. Quilts of it became of value not only for insulation against cold, but also for sound-proofing, a usage that was justified by a Harvard University report (1) in which materials tested were found best in the following order: fiberglass A, kapok, milkweed floss, fiberglass B, kapok felt, fiberglass C, acoustical stonefelt, kunsel, fiberglass D. The least effective materials tested were fiberglass navy wool, foam rubber and hair felt.

In addition, the resiliency and compressibility of milkweed floss produced by mechanized methods of separation have been found to be greater than in any type of kapok (34), and this feature created a great interest in the furniture industry for the floss as filling material. Other possible outlets, if commercial production of the floss is resumed, would include insulation for roofs and refrigerators. And, finally, the sanitary handling assured by mechanization renders the material suitable for use without further processing in bedding, children's toys and surgical dressing.

Milkweed as an Industrial Source of Fiber

The vascular tissue of milkweed stems, as is true of all dicotyledonous plants, forms a continuous ring without distinct bundles. This applies also, of course, to flax, hemp and jute, the world's foremost stem-fiber plants. In the center of older stems is an empty space which is originally filled with parenchyma cells, constituting the pith and occupying about 25% of the cross-sectional area of the stem. The pith gradually disintegrates as the stem matures, but a few fragments of it cling to the surrounding woody ring in mature stems. The woody ring is made up of vessels, fibers and parenchyma tissue; the fibers are approximately 0.5 mm. long and occupy at least 50% of the fully ripened stem. Outside the woody ring, or xylem, is a very narrow cambium layer, surrounded by the phloem tissue which consists of sieve tubes, bast fibers, latex tubes and conductive parenchyma. This bark-like material outside the cambium occupies 10% to 15% of the stem cross-sectional area, and it is the fibers within it that were used by the American Indians.

The author has never considered it desirable to use these stalk fibers for textile purposes, as was done by the Indians, for many other plant fibers are much superior. For the same reason utilization of the stalks for insulation purposes, compressed board, paper and other products, although possible, also does not appear to be the most desirable application. What is necessary for economically successful utilization of milkweed stalks is the production of additional synthetic products. Such additional products from the stalks are offered by the fact that the stalks can be split into two fractions—one, containing the bast fibers, representing 10% of the stalk, and the other the lignin fiber, representing 90%. The bast fibers having almost as high an alpha cellulose content as cotton linters, are suitable for making synthetic fibers, such as rayon, while the lignin fibers could be used for making lignin plastics.

The retting process, utilized by industry up to now for separation of hemp bast fiber from the woody or lignin fiber, naturally was injurious to the cellulose in the bast fiber of the hemp stalk, and damaging to the woody fiber. To avoid this, the author and his associates developed and patented a mechanized method of separation wherein the raw material is not exposed to the retting process, and, therefore, the valuable constituents of the milkweed stalk (cellulose and lignin) are not damaged and may be used with advantage for the production of synthetic fibers, such as rayon, or for plastics.

Mankind, in years to come, will depend more and more on raw materials produced as annual crops, and not on crops, such as trees, produced over a period of years. The valuable milkweed stalk, separated by inexpensive mechanized processes into cellulose fibers and lignin fibers, will unquestionably become a raw material of great value.

Milkweed as a Source of Oil, High Protein Meal and Wax

In 1938 the Milkweed Products Development Corporation established a research fellowship at Iowa State College.

Ames, Iowa, to promote extensive studies of oil, wax and other by-products derived from milkweed. The results confirmed the data of other investigators (19, 25, 38, 43) regarding the chemical properties of these by-products, and also established beyond doubt that mechanical extraction of oil by expulsion methods is not economically sound for commercial production, due to specific physical properties of milkweed seeds. Solvent extraction is the most suitable method, and most solvents used for soybean oil gave excellent results. The yield of oil by hexane extraction was 21.4%. A comparison of the iodine numbers of milkweed seed oil (122.6) and other oils indicate that it is a semi-drying oil, similar to soybean. Milkweed seed oil can be completely deodorized to produce an edible oil (41), and when properly refined will be satisfactory for the manufacture of alkyds.

In an article (24) which also gives data on the physical and chemical characteristics of the oil, on the analytical constants of alkali refined oil and on 52-R-13 long oil alkyds, we read:

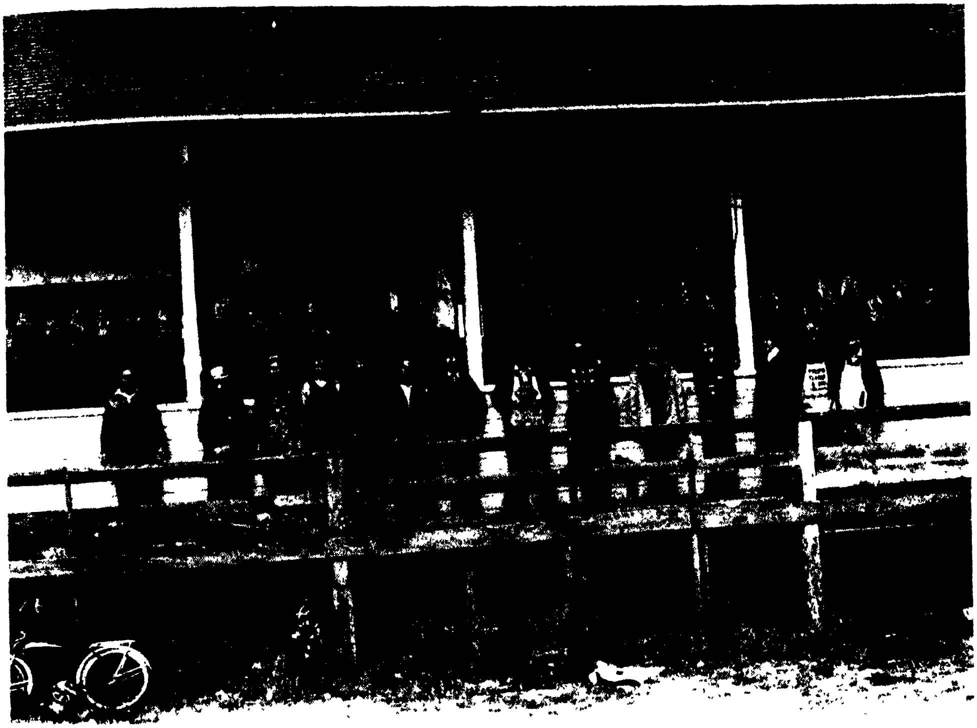


Fig. 5. Milkweed pods air-drying in onion bags.

"While milkweed seed oil does not possess sufficient unsaturation to be rapid drying by itself, the polymeric growth made possible in alkyd resin formation without the loss of unsaturation as occurs in conventional oleo resinous varnish formation, should greatly increase the drying capacity and film hardness. Moreover, the apparent lack of linolenic acid in the oil should make it ideally suitable in alkyds, for high temperature baking enamels, where color retention and flexibility are of paramount importance. The film from milkweed seed oil alkyd showed remarkable resistance to discoloration, and was definitely superior to that of the soybean oil alkyd. . . . Our results indicate that milkweed seed oil is a valuable oil for use in the preparation of alkyd resins".

Since the seeds from which the oil is extracted are high in protein (40%), similar to soybean meal, they can be made into a plastic similar to that produced from soybean meal. The podshells contain a mixture of wax and gums, about 10% by dry weight, and a method of separation has been worked out. "The wax is similar in its chemical properties to Caranauba wax, and has a high melting point" (41).

During World War II, over 2,000.000 pounds of seed were produced, and all were readily absorbed by the private oil industries. The production and utilization of wax and meal was only on a small pilot plant basis; however, basic research shows good potential possibilities for these products.

Production of Milkweed as a Crop

From the agricultural standpoint a number of factors must be taken into consideration before any decision can be reached as to where and how milkweed plants should be cultivated. Numerous investigations have been conducted in this direction and reported in the literature of three countries—United States, Canada, Russia—the findings of which, together with personal observations of the author, are summarized in the following paragraphs. But first let us give some consideration to what has been done in the United States and other countries to investigate and to establish the basic requirements for the cultivation of milkweed.

History. Numerous attempts have been made in the past to cultivate milkweed, and 150 years ago there was controversy between advocates of the plants and scientists who regarded milkweed as useless. Under date of 1810, for instance, we read about the cultivation of milkweed in France (translated) (36):

"I published in 1808 certain observations on the subject of the Syrian Asclepiad. This little work was received with two opposite reactions. The true friends of agriculture, and of public and private economy, appeared to think well of it, and I received many flattering compliments, while those men who never cultivated the soil except in their dreams —undertaking, nevertheless, to be dictators in the field of agriculture, although they never acquainted themselves with it, and over which they pretend to reign as despots, unfurling above their heads the banner of exclusive ambition upon which is written in gigantic letters their favorite inscription—"None may have hopes but ourselves and our friends"— irritated that a mere cultivator dared speak of culture without having humbly solicited them and obtained their permission—they have cried , "Scandal, Ignorance, Charlatanism".

Sonnini states further (36) about the cultivation of milkweed in Germany: "In Silesia, the method of propagation is as follows: Seeding in early spring in a loose and somewhat sandy soil; seeds placed in grooves; germination in 8 or, at the most, 14 days. Young plants need some care; at the approach of winter, young plants are covered lightly with soil which is removed carefully in the spring. The second year the plants reach a height of 2 to 2½ feet, but the roots are still too delicate to transplant them successfully, and at the approach of winter they are protected against cold the same way as the first winter. In the following spring, *i.e.*, the third year, they can be transplanted. This is done best in April. Plants spaced 2 feet apart, giving each plant 4 square feet of area. A loose soil worked the previous autumn is chosen. Roots never placed deeper than 4–5 inches. If precautions indicated are not followed, the plants will be tender and die in a short time. If done properly, plants will throw up sprouts and set fruit. However, the yields will not be very considerable in the third year. On an area of 18,000 square feet, containing 4,500 plants, 90,000 pods obtained".

Kuzmenko (23) gives the following summary and information about milkweed in Russia: "Due to the fact that cultivation and utilization of the Asclepias plant was successful in France and Germany, experiments of cultivation and utilization of this plant can be traced in Russia to the 18th century. . . In 1857, the government gave a license for production and commercial utilization of the Asclepias plant, to citizens Piroschkoff and Hartman (Kiev, Ukraine)".

In the United States a great deal of research has been undertaken since the turn of this century (3, 4, 5, 10, 11, 15, 17, 18). Especially interesting are numerous investigations conducted for many years at the Iowa Agricultural Experimental Station (10, 11, 19). In the annual report (1929-1932) (19), the summary is given as follows:

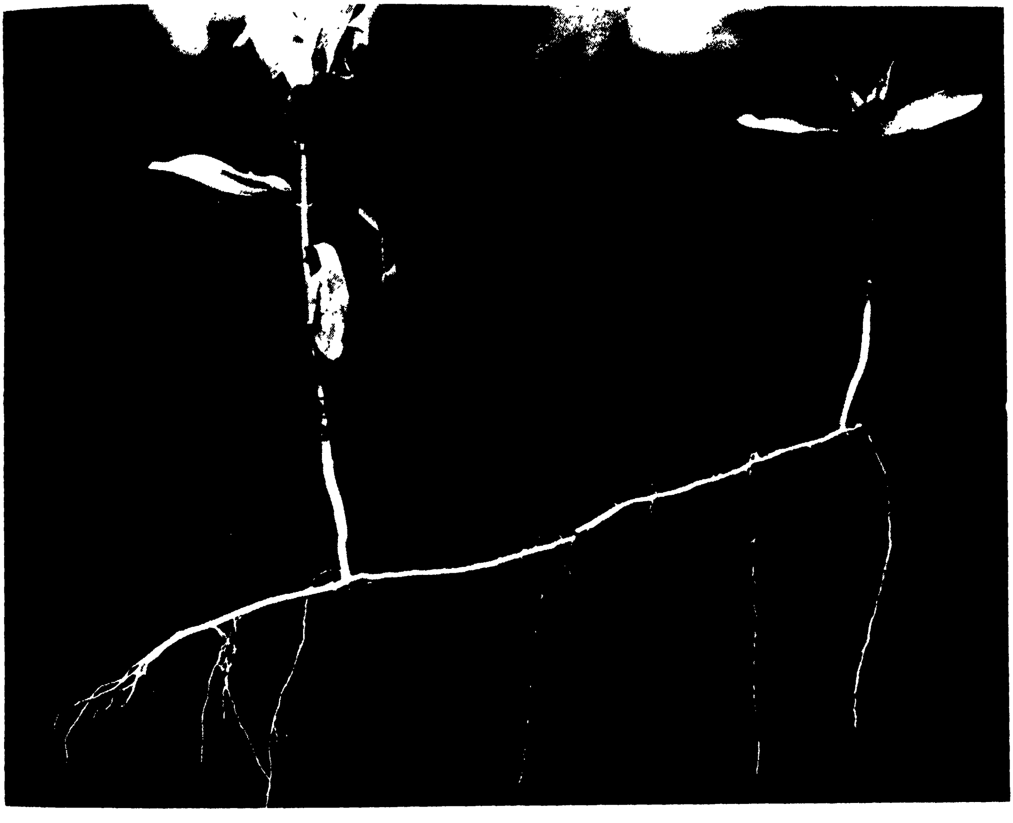


Fig. 6. Two young milkweed plants on a common root, illustrating the usual vegetative method of propagation as it occurs naturally.

"The Milkweed has been grown under cultivation during the past three years. Problems such as propagation, yield and utilization of the various plant parts, have received attention. Yield studies, based upon the experimental plot, indicate a production of 12.5 bushels of seeds, 100 pounds of floss and 1800 pounds of air-dry stem tissue per acre. This yield is low, due to overcrowding of the plants within the row, and represents approximately one-fourth of a possible maximum theoretical yield''.

Moisture. Milkweed plants like moisture, the requirements for which are fairly heavy. Excessive moisture, however, appears to be definitely harmful, and yields are high either on moist soil with a water table not closer to the surface of the soil than one and a half meters, or in regions with not less than 20 inches of precipitation per year. This high moisture requirement is reflected in high transpiration; hence, as the air humidity decreases, the soil moisture of the site needs to be more abundant for sustained good growth. Regions of low air humidity are not unfavorable if the soil moisture is ample and the soil well aerated. Warm, dry soil, resulting from good exposure and drainage, is definitely advantageous. Water-logged soils, on the other hand, cause rotting of the roots. The sub-soil must, therefore, be such as to allow proper drainage, especially during periods of excessive rainfall; for this reason sand and gravel are the ideal subsoils. Fully grown plants withstand drought well, but young plants may easily be burned out by prolonged spells of dry weather.

Soil. *Asclepias syriaca* will thrive on any kind of soil, but it should be planted on poor soil because on rich sites it produces up to seven feet of lush vegetative growth with many stems and branches and an abundance of flowers, but sets few fruits. On light sandy soil it has shorter stems and fewer blossoms, but more fruits. Moist soil with a structure that assures adequate aeration is more favorable than dry soil, whether the soil be sand, sandy loam or clay loam. Loam produces the best growth, muck is very good, sand is good and clay is not so good as sand. The acidity should range from slightly acid to medium acid, or pH 6.6 to 5.7.

Exposure. Milkweed grows best in 30% to full sunlight, and thrives on sites unprotected from direct glare, even in dry warm climate if it has plenty of available soil moisture. In Michigan milkweed was not found in wooded areas, but high quality plants were abundant at the edge of those areas where the soil was richer in organic matter because of decaying roots, leaves and other vegetable matter. A longer growing season in the southern part of the range of *A. syriaca* helps, to some extent, to offset unfavorable site conditions. In the North, where less than 100 days are available for food storage during the growing season, the effects of poor site conditions will be more severe than in the South.

Nutrients and Competition. The absence of certain minerals, for example, boron, from the soil prevents the occurrence of milkweed in some areas. To supplement the natural supply of nutrients, a complete fertilizer is recommended. Clean-cultivated plots show the greatest response to nitrates. If ground-cover treatment is applied, fertilization is often dependent upon the ground-cover vegetation used. Hairy vetch plots, for example, show the greatest response to phosphate and potash. Climson clover, burr clover and blue lupine plots did not display any marked response to either phosphate, potash or nitrate. In experimental plantings all plots in winter-ground covers have been slow to bloom and to put forth fruit when compared with clean-cultivated plots.

Competition must also be taken into consideration when milkweed is cultivated. During the first and second years the young plants can not compete readily with other weeds. Weeding, therefore, is absolutely necessary during that period. When the milkweed plants are well established, other weeds can not successfully compete with them. Experiments at the Iowa Agricultural Experiment Station, Ames, Iowa, and at the U. S. Department of Agriculture at Beltsville, Maryland, have established that it is difficult for milkweed to compete with blue grass the first two years. Canada bluegrass (*Poa compressa*), however, is not so vigorous a competitor as is Kentucky blue grass (*P. pratensis*), since it forms a thinner stand than does the latter.

Propagation. Milkweed is most effectively propagated by means of seed which should be sown either very late in the fall or very early in the spring. Fall sowing should be just before freezing weather so that gemination will not occur until spring. Spring sowing should be done as soon as the soil can be worked in order to take advantage of early rains. Seeding should be preceded by germination tests, rating the vigor on such factors as root length or number of lateral roots produced in a given period of time. Most milkweed seed collected from wild plants germinates very unevenly and slowly. Consequently it is most desirable that seed to be sown in the spring receive preliminary treatment in order to speed up germination or to obtain a greater percentage of germination. On the basis of our experiments the following treatment is recommended:

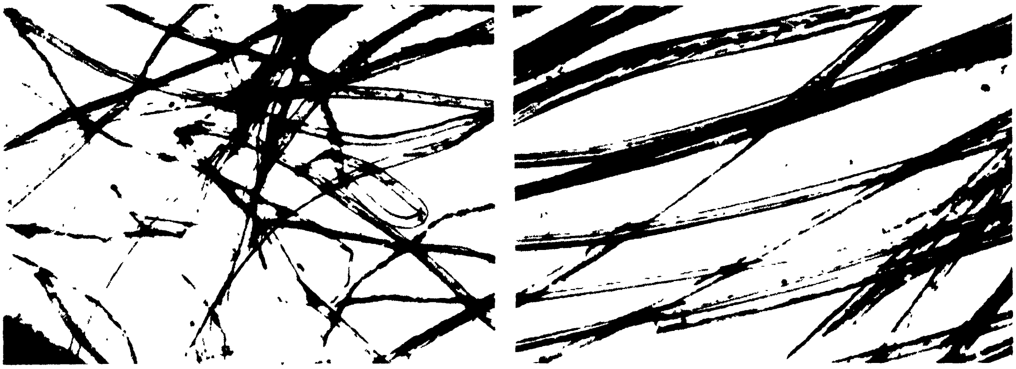


Fig. 7. Photomicrographs of kapok fiber (left), imported from Java, and of milkweed floss (right), collected and processed in America. Because of great transportation costs from Java (12,000 miles), kapok sent to America must first be compressed to weigh 14 pounds per cubic foot, and the high pressure used in the operation results in broken fibers, as shown. Milkweed floss, produced and utilized in America, need not be baled to greater density than five pounds per cubic foot, with consequent elimination of breakage, as shown.

The seed should be soaked in water approximately four hours, then spread out in layers two to three inches thick where the temperature can be kept at 32 to 40 degrees F. The seed must not be permitted to heat during this treatment and should be kept at this low temperature 20 to 30 days; a longer period will give somewhat better results, but even a shorter period will be beneficial. During this time the seed should be stirred occasionally and kept fairly moist. About a week before the seed is to be sown it should be permitted to dry sufficiently so that it will run through a drill or planter. It must not, however, be allowed to become absolutely dry.

Other methods suitable for improving the germination of milkweed seed previous to planting at half-inch depth are:

a) Scarification by abrasion in five degrees—very heavy, heavy, medium, light, very light.

b) Scarification by sulphuric acid

solutions of 5%, 10% or 20% strength for 10, 20 or 40 minutes, then washed.

c) Shaking the seeds vigorously at least 20 minutes in a Mason jar so that they strike the side of the jar with considerable force. A Peerless Mixer can be used for this treatment on a large scale, one revolution every two seconds. This treatment, like scarification, ruptures the inner seed membrane and permits the radical to emerge through it.

d) Freezing of moist seed for 48 hours at 20 to 30 degrees F.

e) Storage at 41 degrees F. for 30, 60 or 90 days.

f) Exposure to infra-red heat one foot distance for five, ten or twenty seconds, one, five or ten minutes.

g) Hot water bath at 100 to 120 degrees F. for eight hours.

The best results have been obtained with cold treatment of moistened seed. The Department of Agriculture, Canada, reports that seeds of *A. syriaca*, soaked in water four hours and then held at 1 degree C. for 25 days, gave 87% germination, and that seeds of *A. incarnata* under the same treatment gave 91% germination. Germination of untreated seed of the two species was 10% and 15%, respectively. In this particular experiment the seed was sown one-quarter inch deep in flats in the greenhouse.

Milkweed is self-propagating also by its rhizomes and is capable of producing suckers two feet from the parent plants. Such propagation is satisfactory for repeatedly raising crops provided the new shoots are confined to rows by cultivation of the soil between them. Artificial vegetative propagation, on the other hand, is not satisfactory because of the well defined rest period needed by the roots. Whether propagation is by seeding or by sprouts from the rhizomes, cultivation between the rows is desirable, and the rows should be maintained about two feet apart.

Other Considerations. Agroecological studies must be taken into consideration in appraising the results obtained so far in cultivating *A. syriaca* and in pursuing such cultivation in the future. Its wide natural range points almost certainly to the existence of ecotypes, and some of these may be very important in developing this species as a crop. In Kansas alone, for instance, there are over 60 species of Asclepiadaceae, and that State, therefore, should be very fertile in yielding various strains. This applies also to the closely related species, *A. Kansana* and *A. speciosa.*

In addition to the greater suitability of particular ecotypes, there are, of course, the factors of temperature, soil composition and bacterial content, humidity, *etc.* These may have accounted for some of the negative results obtained in attempts to grow the plants in such separated areas as Alabama, Maryland and North Dakota from some of the two million pounds of seed obtained during the war in the processing of the floss.

Economics of Production

According to the author's personal observations (3–5), which are in accord with those of others who have given study to the matter (10, 11, 19), an acre of land should theoretically produce one milkweed plant for each square foot, or a total of 43 560 plants. On the presumption that the dry weight of each stalk would be about one-eighth of a pound and that the stalks consist of 10% bast fiber and 90% woody fiber, an acre of plants would yield 5,445 pounds of dry stalks which would break down to 544. pounds of bast fiber and 4,901 pounds of woody material. The yield of pods per acre, on the basis of two pods per square foot of land and varying according to the size of the pods, would range from 1,089 to 1,742 pounds. Three pods per square foot would produce from 1,634 to 2,614 pounds, according to size.

From 100 pounds of green pods there can be produced 12.5 pounds of oven-dry floss, 23.4 pounds of oven-dry seeds, and 18.8 pounds of oven-dry pod shells. On the basis of two pods per square foot, each acre would yield 136 to 237 pounds of floss per acre; three pods would give 204 to 326 pounds; and the average would be 225 pounds of floss, 450 pounds of seed, and 335 pounds of pod shells. These three products would find a receptive market in various industries, and the revenue to be realized from them is estimated thus:

225	pounds of floss @ $0.43, the average price in 1948 and 1949	$ 96.75
450	pounds of seed @ $0.05, the average price in 1948 and 1949	22.50
544	pounds of bast fiber, containing 90% cellulose for producing synthetic fibers, @ $0.04, the price of comparative raw materials	21.76
5,236	pounds of woody fiber (4,901 from the stalks, 335 from the pod shells) @ $9.00 per ton, the average price of similar material	23.40
Total estimated revenue per acre		$164.41

The above total represents the value of raw material obtainable from an average acre and allows ample margin for processing on the part of industry with a profitable return to the farmer when compared with the average yield of other crops, especially on submarginal lands ideally suited to milkweed but not favorable for such other crops.

Summary

The venture into industrial harvesting, processing and utilization of milkweed during World War II established the following facts:

a) That the principal products of industrial value to be obtained from milkweed plants are floss from the seeds borne within the seedpods, and bast fiber from the stalks to serve as a source of cellulose.

b) That by efficient separation of floss from seeds and podshells, the next most important product, the seeds themselves, which are a potential source of oil, can be obtained without significantly increased cost.

c) That wax, to the extent of 5% by weight, can be extracted from the podshells as a third by-product in obtaining the principal product, floss.

d) That, since the main products, floss and fiber, are bulky, the plants must be produced as an agricultural crop and not collected from wild-growing material.

e) That these main products can be obtained by mechanized separation, the milkweed gin doing the work of 1,500 men at hand labor.

f) That there are established markets for the main products—floss, fiber, seed—once their value in competition with similar products is accepted.

g) That if mechanization can be extended to planting, cultivating and harvesting the crop (pods and stalks must be collected separately), we shall have a completely mechanized industry that will contribute much toward meeting the world's ever increasing demands for plant products.

h) That the rubber obtainable from the latex, and considered by other investigators in the United States, Canada and Russia as the most important product to be obtained from milkweed, is only of minor value and can scarcely be seriously regarded as a potential source of industrial rubber.

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Utilization Abstracts

Bamboo Paper Pulp. Experiments are being conducted in Guatemala to supplement the citronella (*Cymbopogon Nardus*) bagasse now used in the paper mill at Los Cerritos with pulp obtained from an introduced species of bamboo, *Bambusa vulgaris.* This investigation was begun in March, 1949, with nursery plantings of this Madagascan species which, since its introduction of unknown date, has spread throughout most of the well-watered parts of the country from sea level to altitudes of around 5,000 feet. (*For. Agr. 13: 143. 1949*).

Bamboo Blowgun. In June, 1949, Dr. Bassett Maguire of the New York Botanical Garden returned after nearly eight months exploration for plants in Venezuela. Among the approximately 12,000 herbarium specimens which he brought back were specimens of the giant blowgun bamboo, *Arundinaria Schomburgkii,* only the lowermost internode of which, sometimes attaining a length of 20 feet, has been used by the Indians of a single remote jungle tribe, the Maquiritares, for their blowguns. Specimens of this giant grass had not been brought out of South America since the plant was discovered by Robert Schomburgk in 1839. It was located on Cerro Marahuaca and is known to the Indians as "curata", to the Venezuelans as "coriza".

"The Piarora Indians, north of the Maquiritares, are the only ones in this region known to make curare, the poison with which their neighbors tip their blowgun darts. Extensive trade goes on in these two products, both between these tribes and with others, all the way across the continent, until both blowguns and curare from the seldom-visited villages of these Venezuelan Indians are found in the markets of British Guiana and other east-coast countries." (*Jour. N. Y. Bot. Garden 50: 164. 1949*).

Manicoba[1] and Mangabeira[1] Rubbers

These two secondary rubbers are obtained from trees that occur naturally in moderate quantities in eastern South America and were used to some extent in meeting the rubber demands of World War II.

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Introduction

During the recent war, with rubber imports from the Far East largely cut off and the Allied stockpile of crude rubber dipping to 45,000 tons in 1943, the United States Government expended considerable effort and money to procure rubber from any and all sources. Even after production of synthetic rubber had become well established, a critical need was felt for certain percentages of crude for compounding with the synthetic. Moderate amounts of plantation *Hevea* rubber were still obtainable from Ceylon, India and Africa, and in North America elaborate but largely fruitless programs were set up to obtain rubber from guayule (*Parthenium argentatum* Gray), a shrub of the American Southwest and northern Mexico, and from the Russian dandelion (*Taraxacum kok-saghyz* Rodin), seed of which had been obtained from Russia. In Haiti a sociological-rubber production program was initiated by the ill-fated Board of Economic Warfare in an attempt to obtain rubber on a large scale from two rubber-containing vines of Madagascar, *Cryptostegia grandiflora* R. Brown and *C. madagascariensis* Bojer. Throughout Central and South America every effort was made to obtain rubber from wild sources. Procurement of *Hevea* rubber from the Amazon valley, the original center of rubber production, was pressed, and the tapping of wild *Castilla* trees was again undertaken in Central America and western South America. Both *Castilla* and wild *Hevea* rubbers were well known, and the tremendous operations directed toward their procurement during the war need not be reviewed here. It might be mentioned, however, that *Hevea* has been introduced and cultivated in various parts of eastern Brazil, particularly in the State of Maranhão and in south coastal Baía near Ilhéus. A few minor plantings of several trees only are located in other eastern and northeastern States of Brazil. The plantings in Baía have been largely for cacao shade, except that since the war there has been some effort to establish rubber plantations there in their own right. The Maranhão plantings were made for the most part shortly after the turn of the century during the first rubber boom. In isolated marshy areas they have seeded naturally to such an extent as to maintain open stands. In Serra de Baturité, Ceará, there has been very sporadic cultivation of *Castilla*.

Little or nothing was known, however, of manicoba and mangabeira rubbers, the trees of which grow wild extensively over the eastern half of South America. The basic facts concerning these two sources, so painfully and sometimes ex-

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[1] Pronounced man-i-só-ba and mang-a-beár-a.

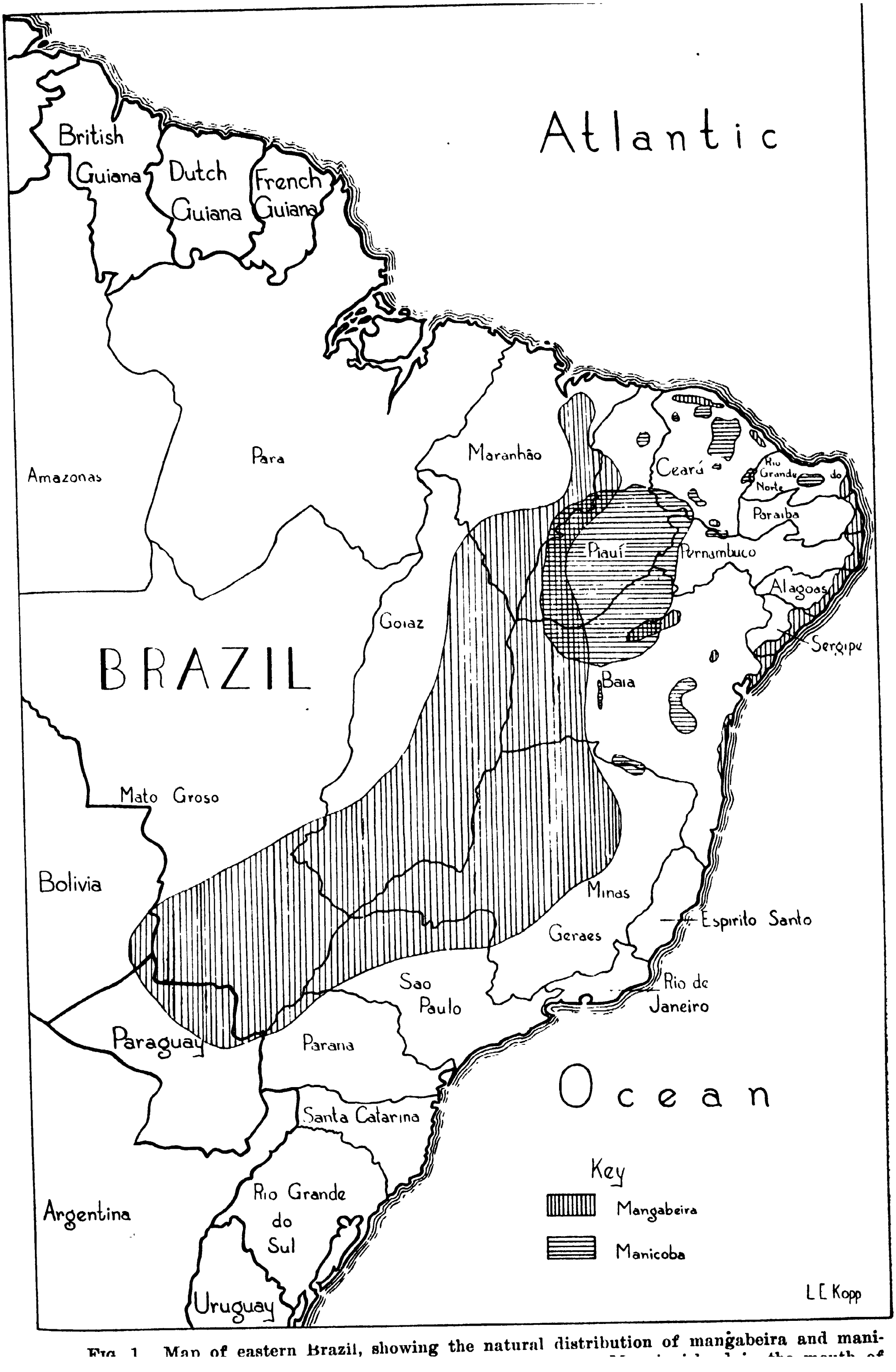

Fig. 1. Map of eastern Brazil, showing the natural distribution of mangabeira and mani-

pensively gleaned during the war years by a corps of North American technicians operating in South America are assembled in this article. During the period 1943–1945 the writer personally visited at least once, every major producing area for manicoba and mangabeira in South America, and later correlated information on these areas as Senior Field Technician of the Non-Amazon Division, Rubber Development Corporation. Since the many reports are now "lost" in Government files, it may be useful to review and summarize the over-all picture of secondary rubber production in eastern South America.

MANICOBA RUBBER

Of the two types of rubber to be discussed here, manicoba rubber, from various species of *Manihot* (Euphorbiaceae), is of the better quality and ordinarily of the greater importance. Untreated manicoba crude rubber, naturally coagulated, has proven exceedingly enduring, lasting for years with inconsequential deterioration under ordinary warehouse conditions. Manicoba rubber appears somewhat more resinous than does *Hevea* rubber, but tests by Government laboratories on numerous samples from a variety of sources indicates inherent quality of the first order. Indeed, could manicoba be as economically produced as *Hevea*, by methods assuring a clean product, and in continuous large volume, there seems no doubt that it would be fully acceptable in rubber industries today using *Hevea* crude. Rubber content of manicoba latex is reported at 15–30%, with resins 3–15%. One species, *Manihot Glaziovii* Muell-Arg., has in the past been introduced from northeastern Brazil into East Africa for rubber production, and both *M. Glaziovii* and *M. dichotoma* Ule were at one time experimentally introduced into Hawaii and various parts of the Far East. The comparative smallness of the trees, their consequent lesser yields, and a horny outer bark inadaptable to precision tapping, rather than inferiority in rubber produced, were the factors mitigating against manicoba's success in competition with *Hevea*.

Manicoba Habitats

The various latex-yielding species of *Manihot* occur throughout the semi-arid caatinga region (3, 6) of northeastern Brazil. In most cases the smallish trees are found on intermediate slopes and elevations, particularly near the base or on the lower slopes of the small mountains (serras) or buttes common to most of northeastern Brazil. Apparently these hills afford wind protection and some subsoil moisture in a subxerophytic environment. Seldom do the lactiferous types occur along river valleys or on ridge or plateau tops. Stands are apt to be scattered into several nuclei within any one State, but may occur with fair frequency, up to 25 trees per hectare, within these nuclei. By and large they exhibit xerophytic adaptations, the most troublesome from the rubber production viewpoint of which is the horny impervious outer bark which hinders tapping. The climate of the region is marked by prominent rainy and dry seasons. During the latter, our late summer and autumn months, manicoba trees characteristically lose their foliage and often become so "dry" that tapping becomes unprofitable. During the few months of rains the manicobas leaf out and grow very rapidly. They are seldom tapped during the rainy season because of agricultural demands on labor and partly because of rain fouling the latex. Further pertinent mention of habitats will be made as the individual species are taken up.

Manicoba Species

The genus *Manihot* is very unsatisfactory from the taxonomic standpoint.

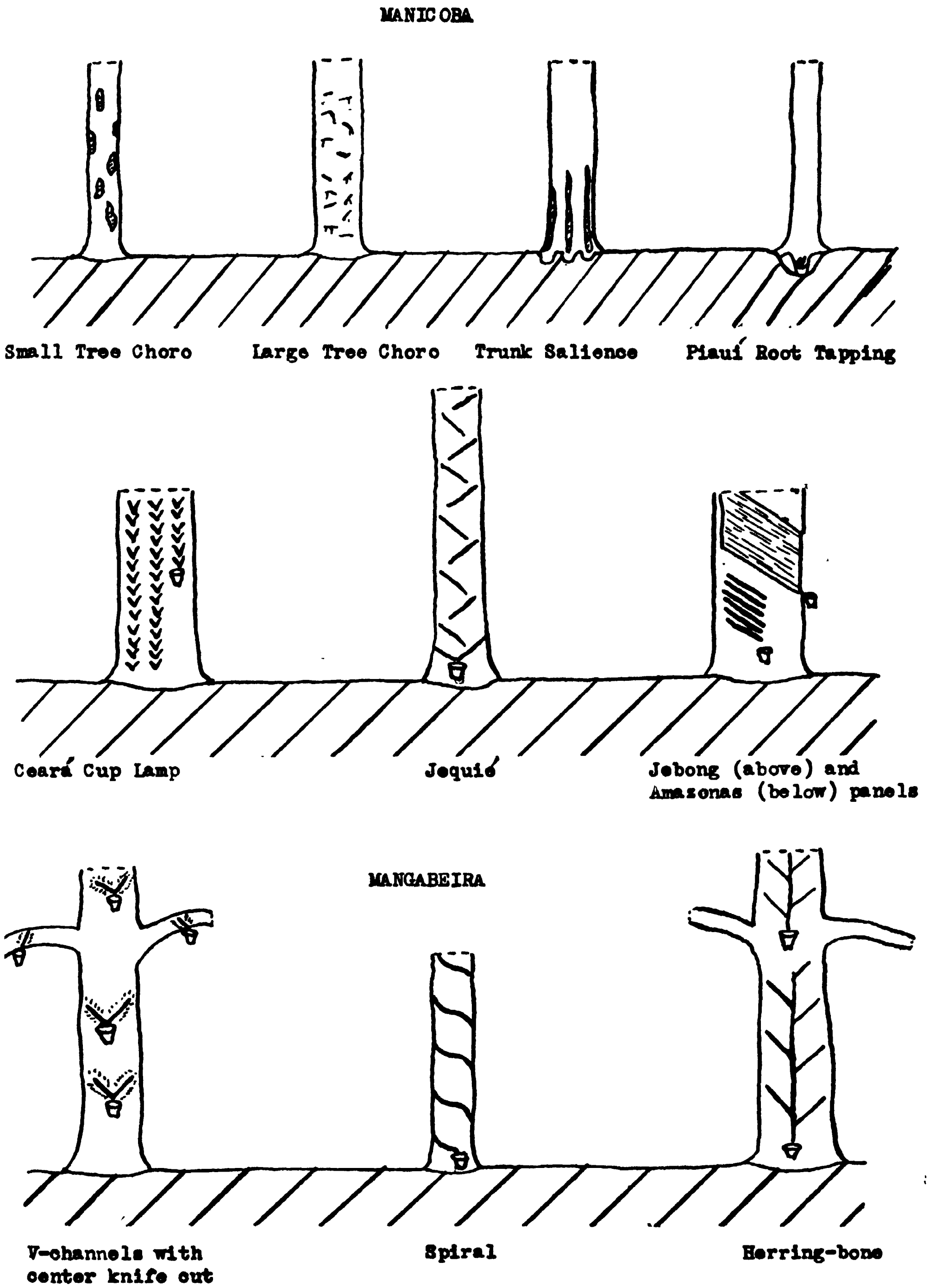

FIG. 2. Some practiced and possible tapping schemes with manicoba and mangabeira rubber trees.

There occur a great many variable forms, and intergradation between these is rampant. Tens if not hundreds of species occur wild (or naturalized? about habitations) throughout northeastern Brazil. For the State of Baía alone some 90 native species of *Manihot* were listed by one of the older German systematists, and although this number is undoubtedly excessive, even a conservative taxonomist would have little reticence in recognizing one-fifth to one-tenth this number. The majority of the species are not lactiferous, and scant attention has ever been given them. Even the lactiferous species, of some economic importance, have not been generally collected nor intensively studied. The famed manioc,[2] or cassava (*M. esculenta* Crantz) is known by hundreds of strains and forms, the relationships of which have never been adequately worked-out. There need be little wonder, then, that considerable confusion exists as to just which "species" is concerned in production and where ranges of overlapping species occur. Each species to be discussed in subsequent paragraphs must be regarded as a plexus of similar variants centering about a certain type or confined to a given region. All degrees of intergradation to other species can usually be found, and marked differences in yield among individual trees expected. As a rule, it is less confusing to refer to the manicobas by their common names, based mostly upon locality, gross similarity in appearance and tapping response, than to the latin name which cannot as yet be precisely delimiting.

Piauí Manicoba: *M. piauhyensis* Ule (northern part of range), *M. heptaphylla* Ule (southern part of range), and perhaps other minor species. *M. heptaphylla* is sometimes rather arbitrarily spoken of as "Sao Francisco manicoba", but in the trade is not distinguished from Piauí production, and is tapped and handled in the same fashion. Piauí manicobas are rather low, small to moderate, monoecious trees, with a smoothish birch-like bark, gnarled and spreading branches, and five to seven palmately arranged leaflets. *M. piauhyensis* usually has the leaflets more or less entire and with an ashy-green cast, while *M. heptaphylla* usually has sinuate lobations toward the tip of the leaflet and a purplish-green bloom. The trees possess a very marked taproot, the source of latex upon tapping. Piauí manicoba is the westernmost of all lactiferous manicobas. It occurs from northern and western Piauí east into southwest Ceará, and southward into western Pernambuco and Baía. Its heaviest concentration is in central and southern Piauí where it is a prominent element of the flora in the most vast of all manicoba nuclei. Within this large nucleus occur many intermittent stands. The area is one of sandy soils, hot sun, scrub forest and low, rounded hills, on the sides of which occur the trees. The sparse and disease-ridden population of the area is with few material comforts and poor and uncertain contact with the outside world. During the dry season even a mule is not to be had for transportation, because of lack of forage enroute. Feudal customs still exist, and the traditions of banditry, vengeance and independence of national mandate have not entirely disappeared.

Ceará Manicoba: *M. glaziovii* Muell-Arg. This is the largest of the manicobas in favorable environments, sometimes attaining diameters of 75 cm. d.b.h. The bark is rather thick, distinctly zoned into a soft lactiferous inner bark and horny outer bark. The leaves are palmately lobed with three to seven, though usually five, leaflets, having a grayish bloom. The trees attain their most luxuriant proportions in the comparatively moist Baturité and Maranguape serras

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[2] Extensively discussed by the present author in Economic Botany 1: 20–25. 1946.

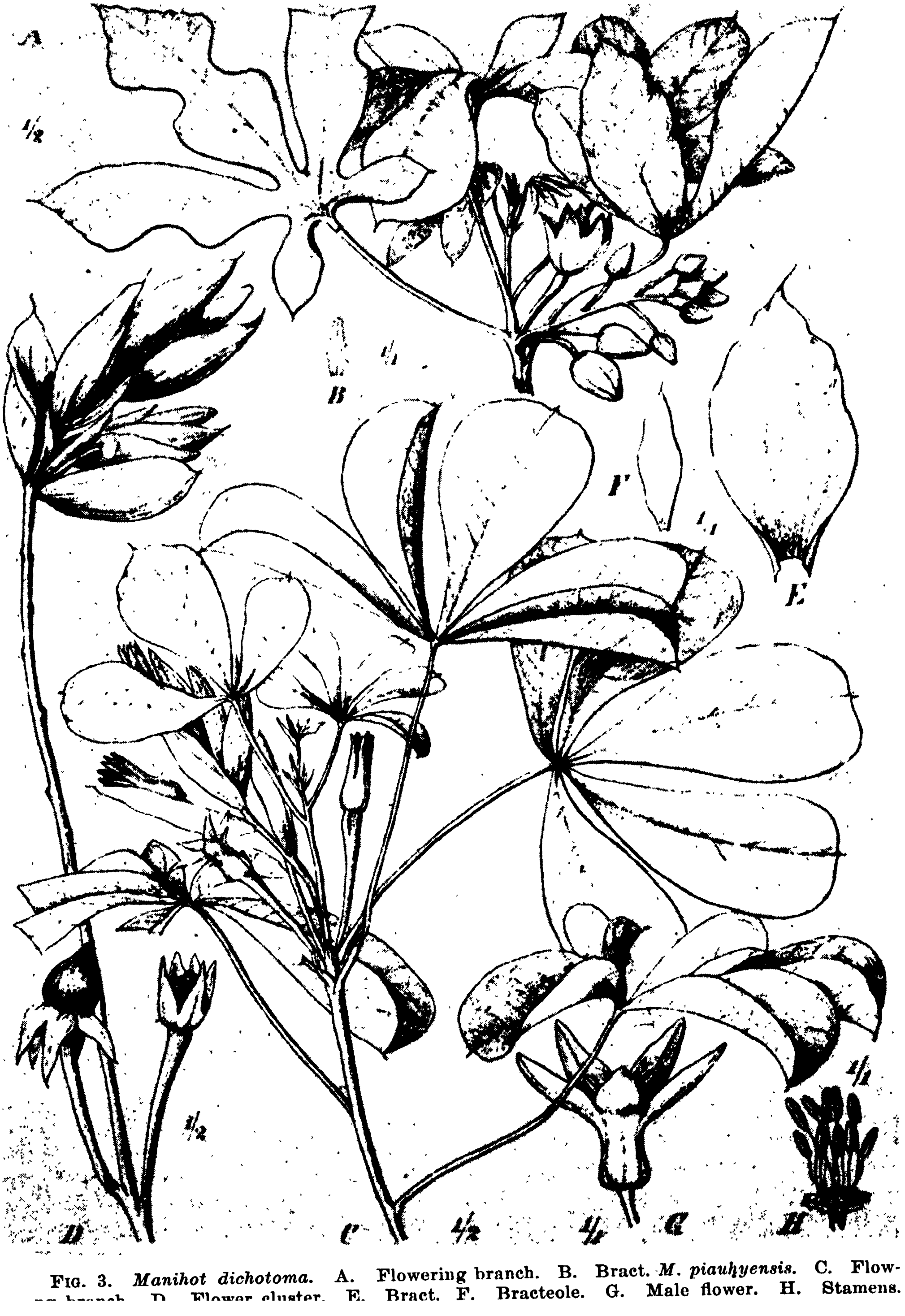


FIG. 3. *Manihot dichotoma.* A. Flowering branch. B. Bract. *M. piauhyensis.* C. Flowering branch. D. Flower cluster. E. Bract. F. Bracteole. G. Male flower. H. Stamens.

just south of Fortaleza, Ceará. Very different in dimension but presumably of the same species, are the small spindly trees of the rocky, dry bases of the serras near São Francisco and Sobral and the south slopes of the Serra de Uruburetama in western Ceará. This nucleus exhibits the opposite extreme in tree size and vigor from the condition found near Fortaleza. On the northern slope of the Serra de Uruburetama; in west-central, south and eastern Ceará; and in western and central Rio Grande do Norte, other serras offer habitat for trees of intermediate size and vigor. All Ceará manicoba is trunk-tapped by a variety of techniques. The area as a whole is arid, although perhaps not quite so inhospitable as is southern Piauí. The people, largely of mixed European-Indian blood with very little negro influence, are among the most industrious and tenacious of northern Brazil. As in Piauí, the entire economy is built about utilizing and storing the wet-season rains, and drought years wreak considerable hardship. Transportation is better than in Piauí, with a rail line and a dirt highway traversing the State of Ceará, and passable highways being found in Rio Grande do Norte.

Jequié Manicoba: *M. dichotoma* Ule. The third and last of the markedly distinctive lactiferous manicoba types is Jequié manicoba, found in a small concentrated nucleus about 75 miles long on the west slopes of the Serra de Maracás just west of Jequié, Baía. Jequié manicoba is a slender but rather tall tree with a very characteristic di- or trichotomous branching. With but little experience it is possible to spot *M. dichotoma* in the scrub forest, leafless during the dry season, by its distinctive outline. The outer bark is horny, but not as markedly so as with Ceará and Piauí manicobas. As with the former, trees are trunk-tapped. Leaves are three to five-lobed with a grayish cast. Here too climate is semiarid with distinct wet and dry seasons. Soils are generally sandy-clay, not so rocky as in Ceará and Piauí. The population of the area, usually bearing a proportion of negro blood, is sparse, for as in Piauí the carrying capacity of the land is low. A tradition of autonomy and rugged austerity has persisted but is giving away as the rail link with the coast permits greater intercourse and commerce.

Exploitation Progress and Possibilities

Piauí Type. Of the three manicoba types described, Piauí manicoba is the least systematically exploited and the most poorly evaluated. This is, of course, a direct reflection of the isolated and inaccessible localities in which it is found. Almost all tapping is carried on by illiterate unsupervised local inhabitants of the caatinga, if and when fancy pleases, and more or less conforming to demand and prices paid. Tappers may organize into gangs to spend weeks in the hills tapping, or more frequently may make daily trips from a permanent habitation. Wants are simple—a few shreds of clothing, a sack of farinha (manioc), occasional wild game and the humblest of shelter suffice. Pay or windfalls in excess of what is needed to supply these fundamentals permit idleness during days that might otherwise be worked. Ills are frequent and competent medical care non-existent. Transportation by truck is sometimes possible during favorable seasons. More commonly it is by mule over roads impassable to motor vehicles. Most frequently the worker simply trudges on foot. Scarcity of transport means poor selection and high prices for the few manufactured articles brought in. Supplies are frequently insufficient. It has never been possible to accurately evaluate the stands of manicoba over the entire area, but, estimating from selected samplings, it would seem that manicoba is encoun-

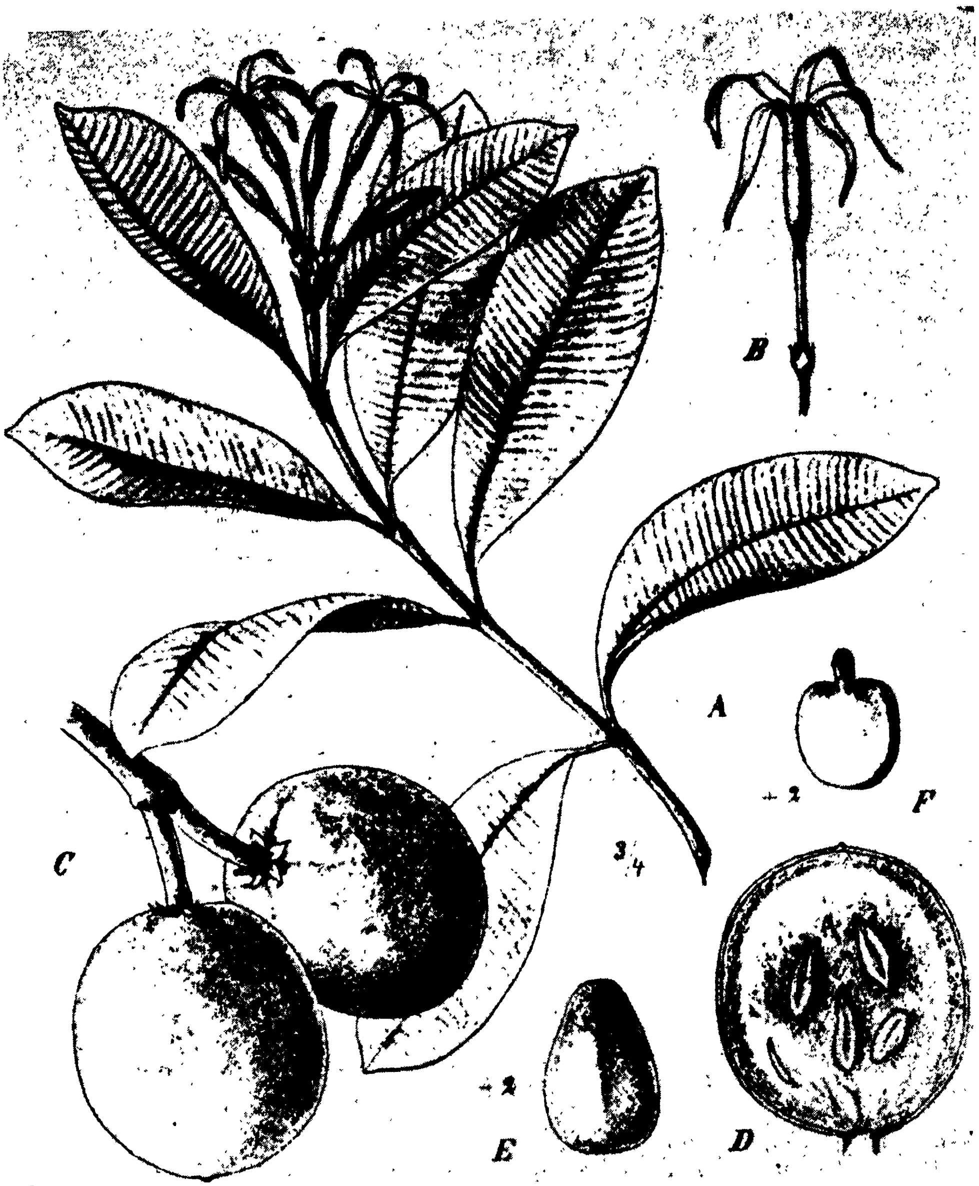


FIG. 4. *Hancornia speciosa.* A. Flowering branch. B. Flower. C. Fruit. D. Section of fruit. E. Seed. F. Young seedling. (*From O. Warburg*).

tered with moderate frequency in a fairly uniform series of clusters centering about the rather indistinct serras. It is not unreasonable to suppose that more than 50% of all usable wild trees were located and tapped during the war years, with the terrific pressure for rubber that existed then. Under most vigorous exploitation production from wild sources can never amount to more than a few hundred tons annually.

Ceará Type. Ceará manicoba is much

better known and more accessible than is that of Piauí. Transportation, supply and labor difficulties are not so great. In most localities perhaps 90% of the worthwhile trees were tapped under wartime pressure. Production of not more than 500 tons annually of all grades is possible from wild sources. Since this area has been treated by Cutler (2) in some detail, it is unnecessary to dwell further upon it here.

Jequié Type. Jequié manicoba, being confined to a comparatively small section of the State of Baía, can be the most accurately evaluated of all manicoba stands. Labor is unavoidably scarce, due to low carrying capacity of the land. Quoting from my Rubber Development Corporation Report 15 of March, 1944, on the Jequié area: "There is more of a labor shortage north of the Rio de Contas than in the southern section. The opinion most often expressed by dealers is 'give us a good price and we will find plenty of labor'. In other words, existing labor needs continuous 'organizing' into a functioning unit. It seems that the situation is much the same as that found in Maranhão, where the fact of 'underpopulation' is used as an excuse for a number of things, but where there are sufficient idle hands to accomplish a great deal, if set to a particular task. True, the municipality of Maracas, for example, is 'underpopulated', (as well it might be, for, banditry aside, . . . sertão country in its present state of development cannot support much of a population . . .), but the barraconista of Salgada finds no difficulty in getting 40 men to working rubber when it looks like profitable business. Nor do many fazenda owners and merchants report a shortage of workers. In most cases where there is a shortage of workers the reason is that the country cannot support more. Thus, before any idea of introducing laborers to such a zone is considered, what is going to happen to them must be thought-out. It is not merely a simple matter of transporting so many souls to a given locality. . . . Housing, food, water, contentment, jealousy of other inhabitants, animals, tools, clothing, communication, sufficient and enduring source of livelihood, *etc.* are each as significant to the worker as rubber. There are a great many facets that go to make up life or even existence anywhere, many of which are not foreseeable; and it is especially risky to tinker with the natural balance of life in a marginal area where a small error in calculation may have far-reaching and disastrous effects. Thus any importation of rubber labor to the Maracas area should be done cautiously, preferably under the guidance and at the responsibility of an established individual of the area, and in small quantity of a few workers at a time.

Labor working rubber in the Jequié region is the same that also must do agricultural work during the rainy season, *i.e.*, it is diverted to rubber work when nothing more pressing or desirable is at hand. Competing enterprises against rubber for labor, other than the necessary agricultural work, are work on Federal road and railroad projects, and extraction of ouricouri wax . . .".

Due to a thick impenetrable scrub undergrowth, necessitating cutting one's way to the manicoba tree, not all high-yielding trees were tapped even under wartime pressure. Along the Rio de Contas valley and south of this perhaps 90% of all trees were tapped, while to the north in the municipalities bordering Maracas perhaps 60–70% of the trees were exploited. Production of Jequié sheet from wild sources cannot exceed 300 tons annually.

Tapping Methods

Since each tapping scheme varies with the species in question and in accordance with local custom, few general statements can be made. With all lactiferous plants, yields are best in the cool of early morning, so that tapping is best started at daybreak and not continued past noon. The difference in yield between early and late tapping is not so marked with manicoba, however, as with mangabeira.

Fig. 5 (*Upper*). A gang of Piauí rubber tappers in manicoba country.
Fig. 6 (*Lower*). Small dealers holding dried Jequié sheets of rubber ready for export.

Piauí Manicoba. With Piauí manicoba, unlike all other types, the root alone is ordinarily tapped. Occasionally a few longitudinal cuts are also made on the lower trunk, but even illiterate tappers seem to realize that the small additional yield thereby gained is not compensatory because of permanent damage to the tree. The tapping routine, in brief, is as follows. A hole is dug in the sandy soil at the base of a selected tree.

This is ordinarily done with the tail end of the elongate tapping tool (lega) and exposes the prominent taproot. The hole is lined with a chalk-like dust (tabatinga) to prevent undue adherence of sand grains to the latex soon to fill the hole. A crescent-shaped gash one-third encircling the upper part of the taproot is made with the U-shaped head end of the lega. Flow of latex is immediate and lasts for several minutes. Under ideal conditions with high-yielding trees 100 cc. or more latex may accumulate in the dust-lined hole where it coagulates naturally within 12 to 48 hours. Typically the tree is visited again two days later, and the cake (chapa) of rubber removed or a second tapping made on top of it. In northwestern Baía tapping is daily for two weeks, then one set of trees let idle two weeks while another group of trees (estrada) is tapped, after which the first is again tapped daily. Ordinarily two, but sometimes several, tappings may be made to produce a final good-size chapa. Each tapping is made by renewing the cut of the bark on the lower edge of the original crescent. A slice of bark a few millimeters wide and completely tô the wood is ordinarily removed with each tapping. Thus, as tapping proceeds, the hole must be dug progressively deeper, or a new hole must be dug on the opposite side. In the course of a tapping season, from the end of rains until the height of the dry season, a good part of the taproot of the manicoba is apt to become devoid of bark. It is no wonder, then, that mortality among trees is high, with few surviving many years of tapping.

Ceará Manicoba. Ceará manicoba is tapped in several manners, depending upon differing environmental conditions and partly upon custom. Cutler (2) has described and figured the different tapping systems of Ceará, so that only brief mention is necessary here. With the large trees of the Serras of Baturité and Maranguape near Fortaleza, V-shape notches up to 15 cm. across are typically hacked with a machete, and a tin latex cup inserted in the bark below the angle of the V. On large trees several cups may be placed, with yields of several cubic centimeters of latex to each cup. Subsequent cuts are made a centimeter or so below the previous one, until the series of tapping wounds runs to the base of the tree. Thereafter a new series is started in an adjacent bark area. Tapping is typically daily except for weekends, holidays or rainy days. Jebong tapping, as practiced on the *Hevea* plantations of the Far East, is possible but not practical because of the care that is needed. Amazonas panels (slanting parallel cuts with narrow strips of bark between) have been tried but have never been widely accepted.

Trees of drier localities, such as near Assaré and in eastern Ceará–western Rio Grande do Norte, may simply be hacked with a machete, and the exuding latex let drip over the bark. At two-week intervals the strings of coagulated latex so produced are hand picked from the bark to be sold as tear drop (choro) rubber, a low quality low-price type. In the drier parts of the Serra de Uruburetama of western Ceará and the Serra de Santâna of Rio Grande do Norte, where trees are extremely small and climate arid, entire sections of bark are hacked from the small trees. At about two-week intervals the choro rubber is picked from the edges of the wound or from drippings on the bark. With the small yields obtainable this system of bi-weekly visits is the only practical one over the rough terrain.

Certain moderate size trees of the Serra do Machadô west of Canindé and elsewhere are treated somewhat as is Piauí manicoba. A tabatinga-lined hole is dug at the base of the tree, but instead of tapping the root, vertical saliences of the lower trunk are opened, resulting in

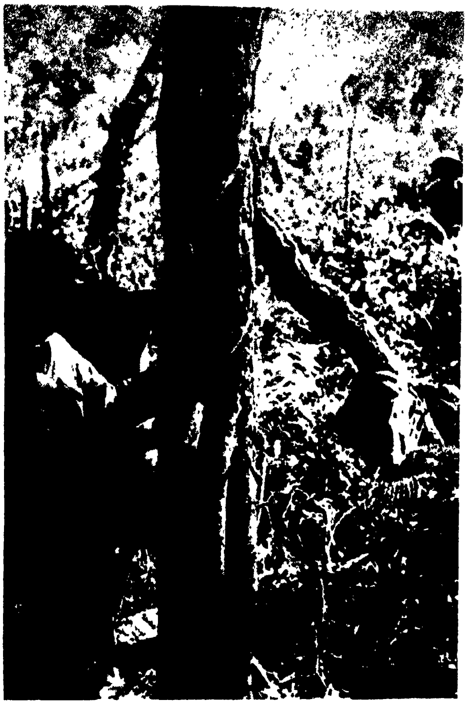


FIG. 7 (*Upper left*). Jequié tapping knife and Jequié manicoba tree at first tapping.

FIG. 8 (*Upper right*). Herring-bone tapping of a large mangabeira tree in northern Paraguay.

FIG. 9 (*Lower left*). A Jequié manicoba tapper and his son.

sufficient flow to form a chapa plate. Tapping is at irregular intervals, and renewal cuts are made at the margins of the old wound.

Jequié Manicoba. The tapping system practiced in the Jequié area is rather unique for manicoba and greatly resembles a refined form of that used with chiclé (*Achras zapota,* chewing gum) in northern Central America. It is severe but perhaps the most feasible for the area where daily or even weekly tapping is impractical. Again I quote from my Report 15 of March, 1944: "The technique of tapping Jequié manicoba presents an interesting case of the powerful influence of custom and teaching on the habits of a region. Other than the fact that back before the first rubber boom Frank introduced the present system of tapping on a region where nothing was known of manicoba or rubber tapping, there is no apparent reason why this distinctive system, different than that used in every other manicoba district of Brasil, should have caught on in preference to others. There seems no logical reason why tappers should today insist on using a cylindrical 'canuto', thus having to slice by hand a cylindrical-shaped coagulum, when flat coagulating pans or any available vessel would serve equally well or better. Frank was a rubber pioneer in a field that was new: he inaugurated a system he thought good, both for Jequié and Hawaii. This system is undesirable from some standpoints, highly desirable from others. The system caught-on (there being no knowledge of others, hence no choice), has 'stuck' ever since. Father has taught son for three generations the details of the Frank tapping technique, and now even should change be desired, the biggest — (propaganda barrage) — would scarcely sway the system with roots so ingrained in the custom and economy of the region. We can well be thankful that Frank was an intelligent man, introducing a system that produces a product superior to that of any other manicoba region. And for the Jequié region, who can say (without years of experimentation) but that it is the best all-around system.

"The Jequié system of tapping is—shown—. The entire tree, from uppermost branches to base of trunk, is tapped by a series of zig-zag cuts by the tapper, who climbs the tree or may boost a boy up for tapping the higher parts. Usually these zig-zag cuts do not meet, but a small area of bark is left between them over which the latex runs, being caught below by the following cut or cuts. This, when practiced, is, of course, helpful to the tree in that the conducting system of the tapped bark is not entirely disrupted.

"If intelligently done, this tapping is practiced only on one half of the tree: a continuous panel of untapped bark will remain on the back side. Tappers have found that if tapping is done on all sides, the tree will die.

"At the base of the trunk a large V-cut is made (usually three-fourths around the tree), to act as a final channel for catching all latex dripping from above and for conducting the latex to the single latex cup located at the vertex of the V.

"The tapping cuts are made with a small knife locally made. This knife has a small curved handle just large enough to fit the palm of the hand, a sharp, very narrow V-shaped head somewhat like that of the Hyde modified Amazonas knife. The tapper, descending the tree from above, makes the zig-zag cuts with a series of quick sweeping thrusts. These cuts reach to the wood, certainly must be damaging to the tree (especially considering the large number made at one tapping: the bark of a tree, being gashed open from top to bottom, demands much of the tree for good healing).

"On trees previously tapped, especially deep cuts (often into the wood) must be made in order to insure flow down the channel of the new cut, rather than drip into old channels. On heavily tapped trees many extra cuts must often be made to conduct dripping latex into proper channels.

FIG. 11. Mangabeira trees on Boipeba Island, Baía.

"In cases where the descent of the tapper is not rapid enough to reach the base of the tree before the flow of latex from the upper branches, he may temporarily locate a latex cup high on the trunk to catch this latex. After continuing the tapping channels to the base of the tree, he withdraws this latex cup, emptying its contents into the one located at the base of the trunk. If further tapping is then still required on the higher parts of the trees to conduct latex properly to the base, the tapper covers the basal cup with a hat to avoid having cuttings of bark fall into it.

"Latex continues to flow from the tapping cuts for about five minutes, anytime after which the latex can be collected. In practice the tapper taps as many trees as he has latex cups (usually about 35), then returns in the reverse order to gather the latex (last tree tapped first visited on return). Sometimes he may send a boy to gather the latex".

Coagulation of Latex and Treatment of Coagulum

In all cases manicoba latex is let coagulate naturally without addition of any coagulant. Coagulation is normally rapid and seldom takes 24 hours. Quite probably oxidation and evaporation are more effective in causing coagulation than is acidification by fermentation, for thin layers of latex will coagulate within a few minutes before any microbial activity could be overly influential. After coagulation the coagulum is cleaned if necessary, then dried in the shade for a few days to several weeks before selling. Ultimate price received will depend largely upon cleanliness and degree of dryness. Frequently large chunks of coagulum are cut to facilitate drying. Top grades of manicoba crude permit no more than 18% moisture.

Piauí chapa. As has been described, this is rubber coagulated in the tabatinga-lined hole at the base of the tree. Any serum (supernatant liquid left by the coagulum) is absorbed by the tabatinga and soil, so that disagreeable fermentation odors are of less intensity than with cup-lump. If the hole is carefully lined with the chalky tabatinga dust, practically no sand adheres to the coagulum. The dust that does adhere and any chance grains of sand are washed off by severe brushing and scraping under water. The chapa is then dried and marketed. Irresponsible tappers often try to load the chapa with sand, for purchase is on a weight basis. This is commonly accomplished by kicking sand over the chapa between tappings. Buyers soon learn to watch for such tricks, and usually cut large or sample chapas before consummating purchase.

Ceará cup-lump. Where latex cups are used to collect latex, as in the Serra de Baturité, barring afternoon rain, the latex coagulates in the cup. Unless yield is very large subsequent tappings are let flow on top of earlier ones until Saturday when the cup-lump is removed for drying. Serum has no escape and typically ferments to create extremely foul odors. Cup-lump coagulum is clean, however, provided no bark or debris is introduced into the cup during tapping, and of very high quality. Little or no washing is necessary, but drying may be slow unless the cup lumps are sectioned.

Ceará choro. Choro is the dirtiest and tackiest of all manicoba rubber. It has been mentioned that coagulation occurs directly on the unprotected bark or at the edge of wounds. Fragments of bark unavoidably adhere to the rubber as the tears and scraps are torn loose. Moreover, these rubber scraps have remained exposed to the sun for many days, a condition conducive to tackiness. In normal times there is little market for choro, and even during the war great stress was laid on washing and creping this type. Such cleaning was accomplished in Brazil at market centers (Fortaleza and Natal) by passing the choro fragments between two differentially rotating rollers while a stream of water played over the mass to remove loose dirt. Large machines are needed, and the process is too expensive to be economical under ordinary circumstances.

Jequié sheet. Highest quality of all manicoba rubber is Jequié sheet. The preparation process can be outlined by continuing my Report 15 quote:

"The latex cups are then emptied into the 'canuto', a cylindrical, locally made vessel holding from 3–5 liters of latex. All latex is swept from the latex cup into the canuto with the flat of a finger. If the latex of some cups should be partially or wholly coagulated it is emptied into the canuto nevertheless (latex of some trees seems to coagulate more rapidly than that of others).

"The canuto of latex is left to coagulate naturally. Coagulation may occur in as little as a few hours, especially if latex is left in the sun, but 12 hours is considered more or less the average length of time needed. Smaller quantities of latex in open latex cups may coagulate within an hour's time. The coagulation point seems to be reached more or less abruptly after a certain period of organic reaction during which the latex expands and foams. The coagulum settles to the bottom of the canuto, and a colorless supernatant serum remains above. This serum, in the cases seen, amounted to roughly 15–20% of the original volume of latex. It is of no value and is poured off by the tapper.

"The coagulum is emptied from the canuto onto a board or mat where it is 'rotarily' sliced by hand. For this slicing any sharpened knife or machete serves. The sheet resulting from this treatment is still quite soft and wet. It is therefore rolled about a stick, being manipulated to press out excess serum. Afterwards the sheet may be passed through a cylinder, if such is available, to further express liquids. It is then hung in the shade to dry.

"At this stage the sheets are classed as 'borracha da semana' and are still wet enough to undergo up to 50% shrinkage before a thoroughly dry sheet is obtained. The tapper sells his rubber to the 'barraconista' or other dealer in the 'borracha da semana' condition. Occasionally this rubber may be lightly smoked.

"When this rubber reaches the warehouses of the dealers it is hung on racks for further drying, where it may remain for a number of weeks. In Maracás all rubber received is washed overnight in water to soften the resins and to wash off dirt, then cylindered on adequate machines and later racked for drying. The rubber when well dried is ready for shipment to Salvador".

Handling and Marketing

Most manicoba rubber is bought in the interior by the barraconista system. This is particularly true of Piauí chapa. Small dealers in the remote villages or ranches, typically agents of larger exporters, advance supplies to tappers where necessary, to be paid-for in rubber. Rubber becomes currency, and so-many kilos of rubber are worth so-many kilos of food or other necessities. The barraconista, the local buyer or capitalist, sells supplies at as high a price as possible, and pays in produce as little as possible for rubber. These small dealers accumulate quantities of rubber sufficient for shipment, and in turn sell to

FIG. 12 (*Upper*). An interior taboleiro, typical of Minas Geraes and Baía, Brazil, where much mangabeira is found.

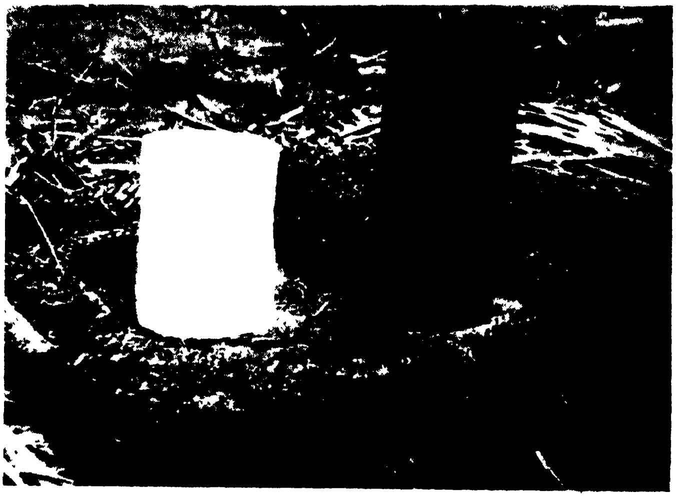


FIG. 13 (*Lower*). A canuto for collecting Jequié manicoba latex (right) and naturally coagulated coagulum (left) after removal from the canuto.

larger exporters. Usually they dry the rubber to attain a higher grade and cheaper shipping.

The rubber is then usually sent by mule train to larger interior cities where agents of larger exporters may further clean or dry it before shipping, usually by rail, to the large ports. Principal export ports are Fortaleza, Ceará and Salvador, Baía. The system of large series of middlemen profiting at the expense of the tapper did not sit well with some North American policy makers during the war. It was soon proven, however, that maximum production at reasonable cost could be obtained only by working within established channels. Each middleman was useful in forcing someone further down the scale to keep production going.

The Manicoba Stands

Mention has already been made of the tremendous variability within the four species of manicoba discussed. There is also variability in yield between individuals of the same species, and between these species and "manicoba brava", *i.e.*, wild manicoba, worthless for rubber. All degrees of intergradation in yield and morphological characteristics can be found between lactiferous and "brava" types. So similar are some non-lactiferous specimens to high-yielding adjacent trees that it is a common sight to see trees experimentally cut by hopeful would-be tappers. Trees so marked with a few experimental cuts are soon abandoned. In some cases after a few tappings giving unsatisfactory yields a tree will become productive enough to be worth future attention. This is due to the phenomenon of wound-response, so well known in *Hevea*. Yields from a newly tapped tree gradually increase to a plateau during the first several tappings. Illiterate manicoba tappers frequently are seen to "amansar" (tame) the wild trees by means of several preliminary woundings before engaging in serious tapping.

Unfortunately little has been done to

FIG. 14 (*Upper*). Tapping the root of Piauí manicoba.

FIG. 15 (*Lower*). Young Piauí manicoba tree in a cleared area.

select stock and improve yields as has been done with *Hevea.* During the first rubber boom many plantings of manicoba were made in Ceará, in northwest Baía and in the Jequié area. Several million manicoba trees are reported to have been planted in northeastern Brazil during the first decade of this century. Plantings were made also in East Africa and the Far East. But the bubble soon burst, and little remains today of the unattended plantings, usually away from the natural environments best suited to the species. Many plantings were cut for fuel or to clear the land again for agriculture. Thus there was no opportunity for constant selection and propagation from selected varieties. Most of the original plantings seem to have been made from unselected seed with no possibility of yield prediction. Plantings made from cuttings gave high mortality, but even with this kind of propagation no marked program of selection was followed. Even the meager plantings initiated during the recent war apparently utilized the cuttings not thoroughly selected for yield.

Heavy tapping during the war undoubtedly caused worsening of the wild stands. Quite naturally high-yielding trees received most frequent and heavy tapping, resulting in death to a large percentage. It is probable that in heavily exploited districts as much as one-third or one-half of the best yielding trees had been killed or were moribund by 1946. Not only were these trees themselves eliminated, but their presumed utility to transmit high-yielding characteristics to offspring was thus cut short. It would appear that only intelligent planting programs can assure significant manicoba production for the future.

MANGABEIRA RUBBER

Mangabeira rubber is obtained from several strains of a single species of *Hancornia, H. speciosa* Gomes, of the Apocynaceae. This species occurs in the wild only, scattered in almost all States of Brazil south and east of the Amazon valley and in northeastern Paraguay. In some locations it attains robust proportions, diameters up to 50 cm. d.b.h. and heights of 15 m. In others it is a spindly willow-like dwarf, usually compensating for its small stature by greater frequency. The bark is thick and soft, possessing a conspicuous cork-layer in old age. It is easily cut with even a dull tool. Latex vessels occur in the inner bark, and once severed, unlike those in manicoba, drain the latex in a sudden gushing flow for considerable distances to each side. Several weeks or months are required to regenerate new latex sufficient for a second tapping, and in dry years only a single tapping may be feasible. Mangabeira branches are typically gnarled and drooping. The simple, opposite, elliptic leaves have characteristic parallel secondary veins. The white flowers are perfect, small, fragrant, borne towards the tips of the finer branches. The fruit is a large greenish berry, becoming brownish or reddish when ripe. Mangabeira latex was in heavy demand during the war years, although this rubber is of inferior quality and less dependability than that of manicoba or *Hevea.* Resin content is usually 10–13% in comparison with the usual 4–5% for *Hevea.* The latex has also been locally used for waterproofing cloth, as a rubber cement, and reportedly as a tonic. The persimmon-like fruit is highly esteemed when ripe.

Mangabeira Habitats

Mangabeira appears to be restricted to poor, porous, sandy soils in localities of moderate to moderately low rainfall. Such areas are marginal grassy forests, sparse parklands or savannah, studded with a loose stand of trees, mostly mangabeira, cajú (*Anacardium,* the cashew) and various representatives of the Dilleniaceae, Malpighiaceae and other families. Mangabeira predominates on flat-topped elevations, known as "taboleiros", having the characteristics just described. These taboleiros, or tablelands, occur intermittently in a narrow belt along the sea coast from Pará and Maranhão, through Piauí, Ceará, Rio Grande do Norte, Paraiba, Pernambuco, Alagôas, Sergipe and Baía to Espirito Santo. Paradoxically they are further found in the interior far from the coastal environment, but again midst similar ecological and soil conditions. Interior taboleiros are located in Maranhão, Piauí, southern Ceará, and extensively in western Baía, Goiaz, Minas Geraes and Mato Groso. Small stands are found to the south in northern São Paulo and northern Paraguay.

In most of these locations agriculture is impossible. Grazing of cattle on open range may be practiced in the more habitable portions. In the latter case an unfortunate concomitant is the annual dry-season burning-over of the land. Belief has it that such burning somehow improves the grass. It does cause tender new leaves to arise, perhaps more palatable to cattle than the coarse dry stalks, but humus is lost, the soil impoverished and arborescent vegetation set back. Only thick-barked woody species survive; mangabeira in such areas may be 25 years old and not more than five centimeters in diameter. Practically no passable roads exist over the loose sand, nor is there sufficient labor available to make and keep up roads. Living conditions are of the most primitive sort. Only the poorest of Indian and negro-blooded people occupy the area. Supplies are almost non-existent, and food and water must usually be hauled in by mule or by human carrier.

The tappers of mangabeira on the more isolated taboleiros lead a semi-nomadic life. Rude mud and stick huts are thrown up for nightly protection, while all members of the group or family scour nearby localities for mangabeira, hoping also to find sustenance—wild fruit, such as cajú, and occasional game. Once accessible trees have been tapped the group moves on to other locations, for at best mangabeira can be tapped only three or four times per season.

Tapping Techniques

Mangabeira must be tapped in the cool of the morning to give profitable yields. Flow is noticeably less after midday and towards the end of the dry season. The latex is white or pinkish, and the rubber produced becomes reddish on the exposed surfaces. Mangabeira tapping is so completely unsupervised and practiced by illiterate people antagonistic to innovation that techniques largely follow local custom with little regard for improvement. The more prominent generalized techniques can be mentioned here, but it must be remembered that local modifications or exceptions to these occur frequently within the ranges specified.

Some of the worst tapping occurs in the backward State of Maranhão, Brazil, and neighboring Piauí. There longitudinal gashes, or scrapings to thin the bark, followed by a series of incisions cause latex to exude and flow down the trunk. This latex may be gathered by a spoon and emptied into a gourd as it flows, or even let accumulate in a hole at the base of the tree. One such tapping makes the tree unfit for any future tapping and often kills it outright. Even roots are sometimes tapped there and in isolated localities along the Baía coast as well.

A more rational procedure is practiced in the coastal areas of Ceará-Baía, although even here local haphazard gashing is not uncommon. A V-channel is pared in the outer bark only, and a knife-edge cut made at the center of this

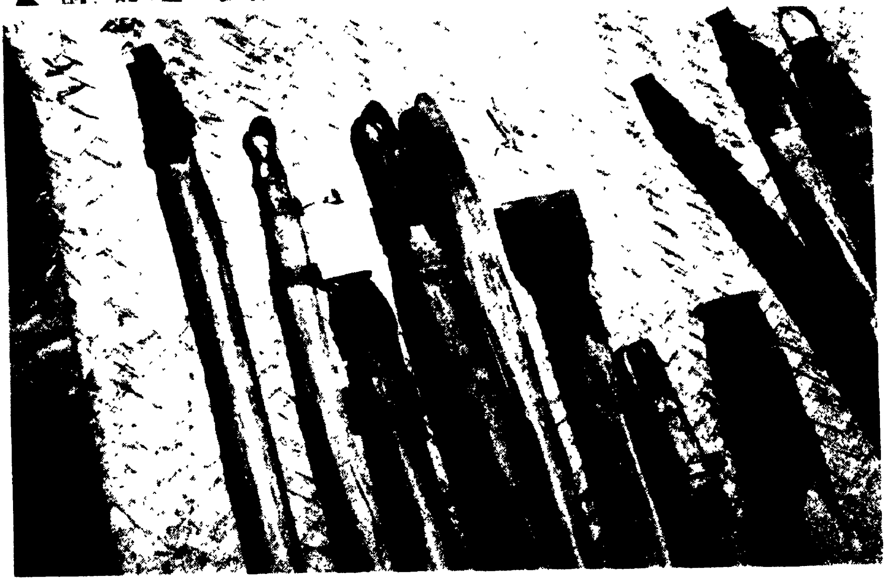


FIG. 16 (*Upper left*). Rolling Jequié coagulum to express water after it has been sliced to sheet thinness with a machete.

FIG. 17 (*Upper right*). A badly scared and therefore nearly worthless mangabeira tree of the west Piauí-Maranhão zone in Brazil.

FIG. 18 (*Lower*). Legas, or tapping tools, for Piauí manicoba root tapping.

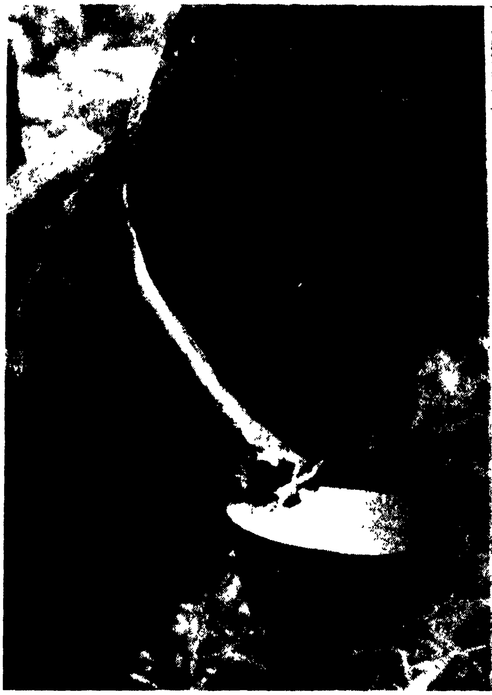
channel to the wood. Several such V's may be made at intervals on the trunk and lower branches. The knife edge cut then severs the latex vessels, permitting sudden copious flow into a tin latex cup or molded leaf inserted in the bark just below the angle of the conduction channel. Very similar is the technique usually employed on interior taboleiros in western Baía, Minas Geraes, Goiaz, Mato Groso and southern Ceará. Specially designed knives with a U-shaped head on one end and a knife-edge on the other are employed. A conducting channel is made in the outer bark by the U-shaped head, followed by severance to the wood with the knife-edge. Unfortunately many careless tappers cut all the way to the wood with the U-head, causing wounds that are slow to heal. At times longitudinal connecting gashes are made between V-channels, so that one latex cup may serve two or more tapping locations.

In Paraguay and parts of Mato Groso and scatteringly elsewhere, a herringbone system of tapping is used on the large trees. An elongate but shallow vertical channel is made into which run several lateral channels from all parts of the tree. The channeling is done with a U-headed knife and is followed by knife-edge cuts all the way to the wood, made with any available blade. Two to four panels of this type are typically opened on the lower trunk, upper trunk and larger branches. The lateral channels are inclined about 45°. At the base of the vertical channel a tin can is inserted in the bark to catch the draining latex. The same vertical channels will serve for several tappings, merely by cutting new laterals. Interval between tappings is typically about six months. With this system as much as five liters of latex can be obtained at a single tapping from a large tree, but a more usual amount would be not more than one liter at the first tapping. With the small trees of the coastal taboleiros, 100 cc. of latex per tree would be an exceptional yield. In some coastal areas (Esplanada, Baía) it is necessary to make a continuous spiral cut from base to tip of the small trees in order to get enough latex to one-fourth fill a single latex cup. Such spiral tapping or a zig-zag modification of it are the dominant tapping methods throughout Sergipe.

FIG. 19. A mangabeira tree near Ituveraba, Sao Paulo, with multiple tappings, as evidenced by the several latex-collecting cups on the trunk. (*Courtesy of Dr. H. C. Cutler*).

Latex Coagulation

Contrary to the simple natural coagulation of manicoba latex, coagulation of mangabeira latex offers many possible procedures, and many uncertainties. Intensive study was directed during the war years towards finding the most suitable coagulation procedure, but no conclusive results were obtained. For one thing, mangabeira latex from different localities gives different quality coagulum with the same coagulant. For another, treatment of the coagulum after coagulation may have more influence than the means of coagulation. Certain graders seem to favor rubber coagulated by one means, while other graders favor another. All-in-all, the most efficient procedure for the undependable stubborn labor is to employ the least expensive and simplest materials. In some localities fine quality mangabeira results, no matter which coagulation technique is used. In others the rubber invariably turns tacky in short order. The various coagulation procedures consist of natural fermentation, boiling and use of alum, salt, acid, various unusual chemicals or smoking.



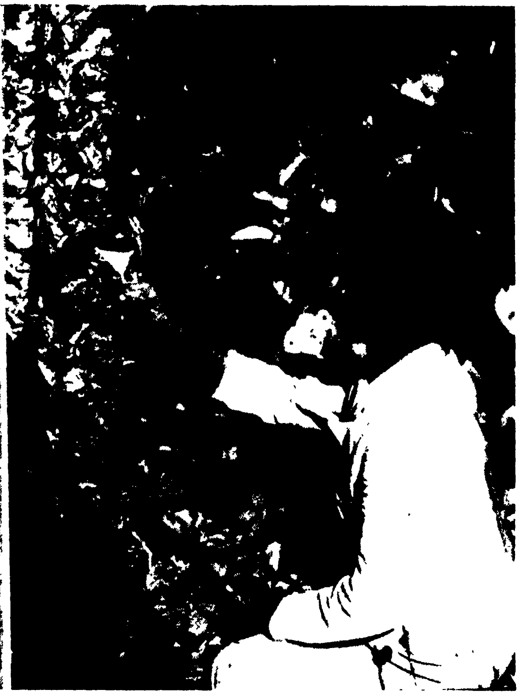


FIG. 20 (*Left*). Good V-tapping and cup collection of mangabeira latex near Axixá, Maranhão, Brazil.

FIG. 21 (*Right*). Typical tapping of manicoba (*Manihot Glaziovii*) south of Fortaleza, Ceará (Maranguape). The small machete in the cutter's hand was used to make the V-cut, and healed cuts from previous tappings are visible on the trunk. (*Photos courtesy of Dr. H. C. Cutler*).

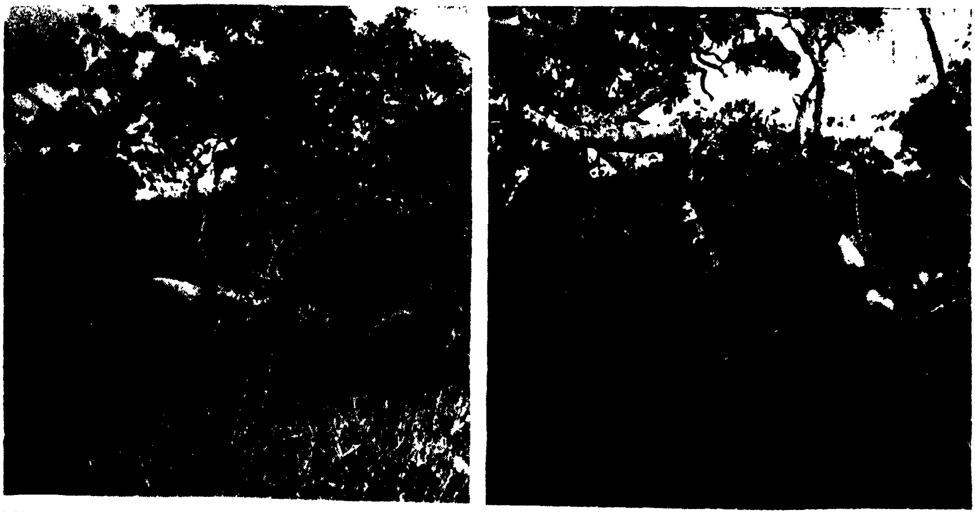
Natural Coagulation. This procedure was intentionally practiced during the war only scatteringly, for mangabeira latex is notably slow to coagulate naturally, requiring days or even months to do so. In a few cases tins of latex have been "forgotten", or left in a truck many days in the sun to coagulate naturally. In all cases of natural coagulation which have come to the author's attention, the rubber so produced was of excellent quality.

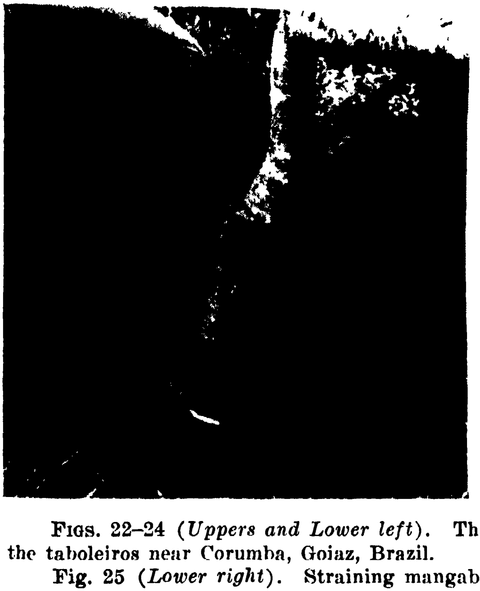
Boiling. Boiling is most commonly practiced on the east coast of Brazil, and here and there in Minas Geraes and Goiaz. Latex, preferably strained and sometimes diluted, is boiled over an open fire with constant stirring. As pockets of uncoagulated latex form within the coagulum they are exploded by the stirrer. Within a few minutes a soft thick coagulum forms, containing in excess of 50% water. Boiling may be accomplished in any kind of container, and in isolated taboleiros is usually in crude earthen pans. To form a higher grade product, such soft coagulum must be pressed free of excess water. In buying-centers water is expressed by passing the coagulum between cylinders similar to the wringer of a washing machine, while on the taboleiros this is commonly accomplished by stamping on it. Heat-coagulated latex was generally found more acceptable than other types by the Salvador grader during the war years.

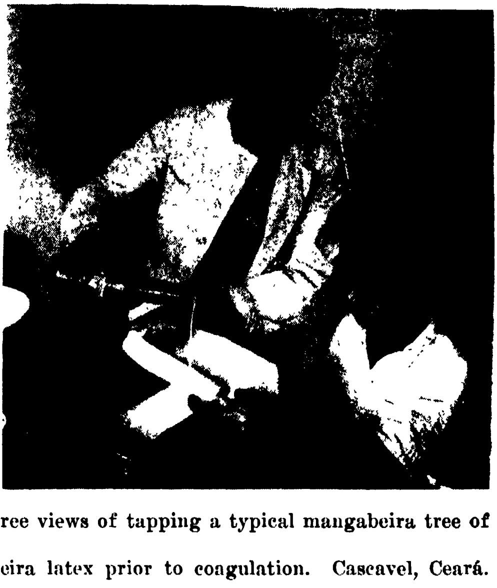
Alum. Alum, or alum plus salt, is one of the most frequently used means of coagulation of mangabeira latex. Coagulation is instantaneous, giving a good workable coagulum with the use of very little alum. Expellation of excess water is necessary as with boiled coagulum and is accomplished by stomping, rolling with a stick, bottle or roller, or in Paraguay by perforating the coagulum with a multitude of fine holes. Before coagulation the latex should be thinned (one to two parts of water to two parts of latex) to permit straining of any debris from it. Copper screen should not be used for straining, for copper is detrimental to all types of rubber. Seldom do local peoples use a measured concentration of alum. A small handful of crystals to a few-liter container of latex is about as precise as the measurement ever is. On the large supervised ranches in Paraguay 1¼ tablespoons of alum plus 1¼ tablespoons of salt were used with a liter of water to make a coagulating solution. This solution was poured over the filtered latex and worked in with the fingers until coagulation occurred. The serum left after coagulation was reused with the next batch of latex. Different latices in different parts of Brazil seemed to require different concentrations of alum to effect coagulation. Although alum is available in much of Brazil and a favorite for mangabeira coagulation through most of the interior, graders discouraged its use, feeling that alum-coagulated rubber had a greater tendency to turn tacky. I have seen crude rubber from Maranhão and Paraguay coagulated with alum, however, that remained exposed to air for years without a trace of tackiness.

Salt. Use of salt as a coagulant has most of the advantages and disadvantages of alum. It is not so quick nor thorough in effecting coagulation as is alum, and labor is likely to use excessive amounts which possibly cause accelerated deterioration of the rubber. Coagulation is best done in non-metallic containers, for a blue dye, produced by tannins of the latex reacting with iron, stains the coagulum when it is left for the prolonged period necessary with use of modest quantities of salt. Salt coagulation has been commonly practiced on the Ceará coast, and scatteringly on interior taboleiros in Brazil. At times sea water has provided the salt solution (Boipeba island, Baía). Solutions locally prepared contain one to two cups of salt dissolved per liter of water, one cup of which is used to coagulate a liter of latex.

Acid. Various acids will cause coagulation of mangabeira latex, but results with locally available acids are uncertain, and this method of coagulation is seldom employed where other means are possible. Juices of lemon, lime and various wild fruits have been tried. The sap of caxinguba (*Ficus anthelmintica* ?) is reported useful, but seldom is this wild fig found in association with mangabeira. Oxalic acid was found to give coagulum of good vulcanization and strength qualities, but unfortunately large quantities of this comparatively expensive ingredient must be used, so that the system has never become practical. Sulphuric and hydrochloric acids are reported usable if care is taken, but even then there is floculation of the coagulum in processing.







FIGS. 22–24 (*Uppers and Lower left*). Three views of tapping a typical mangabeira tree of the taboleiros near Corumba, Goiaz, Brazil.

Fig. 25 (*Lower right*). Straining mangabeira latex prior to coagulation. Cascavel, Ceará. (*Photos courtesy of Dr. H. C. Cutler*).

Other Chemicals. Other chemical coagulants have never proven practical in production of wild rubber. A chemist assigned to study mangabeira latex coagulation during the war advocated use of ammonium chloride, among other coagulants. Use of this chemical is impossible, however, for it is unknown and unobtainable in the remote districts where mangabeira rubber is produced. The same is true of various other reagents; none is suitable unless locally abundant, cheap and simply utilized.

Smoking. The smoking of mangabeira latex by a process similar to that used in connection with *Hevea* latex from the wild, was stressed for a time, but the tediousness and excessive labor of the process make it unacceptable to mangabeira tappers.

Handling and Marketing

Handling of mangabeira is much more difficult than is that of manicoba. In even a few weeks time the rubber is apt to deteriorate markedly, becoming tacky and inelastic. This appears to be more common with mangabeira from the coastal areas of Brazil, particularly if salt- or alum-coagulated, than with mangabeira from Paraguay or interior Brazil. It was found during the war that mangabeira rubber kept continually moist kept better than rubber racked or otherwise exposed to air. Many dealers kept mangabeira sheet in tanks of water until a few days before shipment. Because of the tendency towards deterioration, quick turnover of mangabeira is advisable. It is a tricky rubber, and its quirks are not always predictable, nor their cause known.

Marketing of mangabeira is similar to that of manicoba. Local buyers or agents purchase or trade from isolated tappers at as low a price as possible. Usually rubber so purchased has an extremely high moisture content (60–70%), and must be further dried or squeezed to attain higher grade status. Grading of mangabeira is largely a question of moisture content, for if the latex has been caught in cups and strained before coagulation, there is little chance of many impurities being present. A series of middlemen eventually send the rubber to the port cities where large exporters distribute it to manufacturing centers. In peace time little demand exists for mangabeira except locally. During the war years production could never be pushed to 1,000 tons annually, and sustained production of even a few hundred tons annually for all of South America would be difficult. Certainly mangabeira can never compete with *Hevea* on the world market, in quantity, quality or price. To the best of my knowledge no mangabeira plantings have ever been made. The tree appears too slow-growing and demands too special an environment to lend itself to plantation practices.

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World Production and Consumption of Millet and Sorghum[1]

Millet and sorghum are important food grains in many foreign countries, but they are almost unknown for this purpose in the United States. World production of these two grains averages almost a third of the production of wheat, almost half of the production of rice, and slightly more than the production of rye. Asia, Africa and the Soviet Union produce most of the millet and sorghum grown in the world.

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and
JOHN H. MARTIN[2]
U. S. Department of Agriculture

Importance

Millet and sorghum are grown and used as food by millions of the inhabitants of the earth. They are cultivated by more than one-eighth of the farmers in the United States, but are little known to other Americans because they are usually consumed where grown and do not enter in any large volume into international trade. A large part of the millet and sorghum of the world is produced in Asia, Africa and the Soviet Union where most of it is consumed as food. Much of it is grown where the seasons are too short, or where the climate is too hot or too dry, for other grains to succeed well. World production of millet and sorghum for the period 1934–1938 averaged about 50,300,000 short tons annually, compared with 171,000,000 short tons of wheat, 110,300,000 short tons of rice, and 47,500,000 short tons of rye.

Millet and sorghum have come to be looked upon as "poor man's cereals", and some writers refer to them as "inferior" grains. Probably the principal reason for these aspersions is that some kinds of them have a rather strong taste. When people are given free choice, they seem to prefer such cereals as wheat and rice which are bland and mild of taste. Studies of the nutritive value of sorghum and millet show that they compare favorably in this respect with other cereal grains. In some countries the poorer natives sell rice or wheat which command a higher price and consume the cheaper "coarse" grains.

History

Millet and sorghum are among the oldest of the cereals, and in the ancient world they were common bread grains. Millet was used as food in prehistoric times, and little is known concerning its origin. Some students believe that it was the first cultivated crop, having been grown in the so-called Hoe-Age which preceded the Plow-Age. Its use as a food in India, China and Egypt began before there were written records.

In ancient and medieval times millet

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[1] Contribution from the Bureau of Agricultural Economics and the Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture.

[2] Agricultural Economic Statistician and Senior Agronomist, respectively.

was grown in most of the known world. During the Middle Ages it was one of the principal foods of the poor people of Rome and of Europe generally. During the 19th century millet was gradually superseded in western Europe by wheat, rye, rice, maize and potatoes which usually produce higher yields than does millet. Development of yeast-raised bread was partly responsible for this eclipse in western Europe, for millet does not have some of the qualities required for making a good raised bread. At present, millet's share in world production of cereals is less than in the past, since it has been gradually replaced in most occidental countries by other foods, especially wheat and corn, and, to some extent, by potatoes. Only small quantities are grown now in western Europe where it is used mainly for poultry feed. In eastern Europe millet it still served as a food in the form of porridge and flatbread, or used for making alcoholic drinks. Large quantities are grown and used as food in China, India, Manchuria, Africa and the Soviet Union.

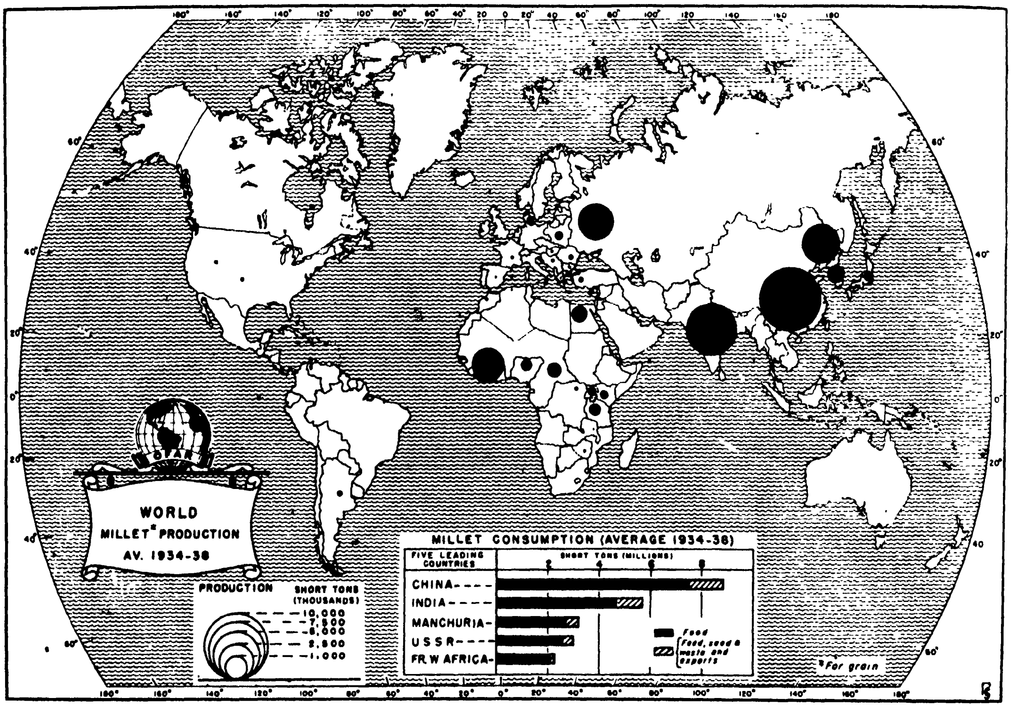

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FIG. 1. The annual world production of millet during 1934–1938 averaged about 26 million short tons. More than 22 million tons were consumed as food, and about 1.5 million were fed to poultry and livestock. China, India, Manchuria, the Soviet Union and French West Africa were the principal producing and consuming countries.

Sorghum was grown in Assyria as early as 700 B.C. Pliny wrote that sorghum was brought to Rome from India, and it was long believed that India was its original home. It has not been found growing in a wild state in India, and it is now thought that it originated in Africa. Doubtless, it has been grown in Africa for several thousand years. Sorghum apparently did not

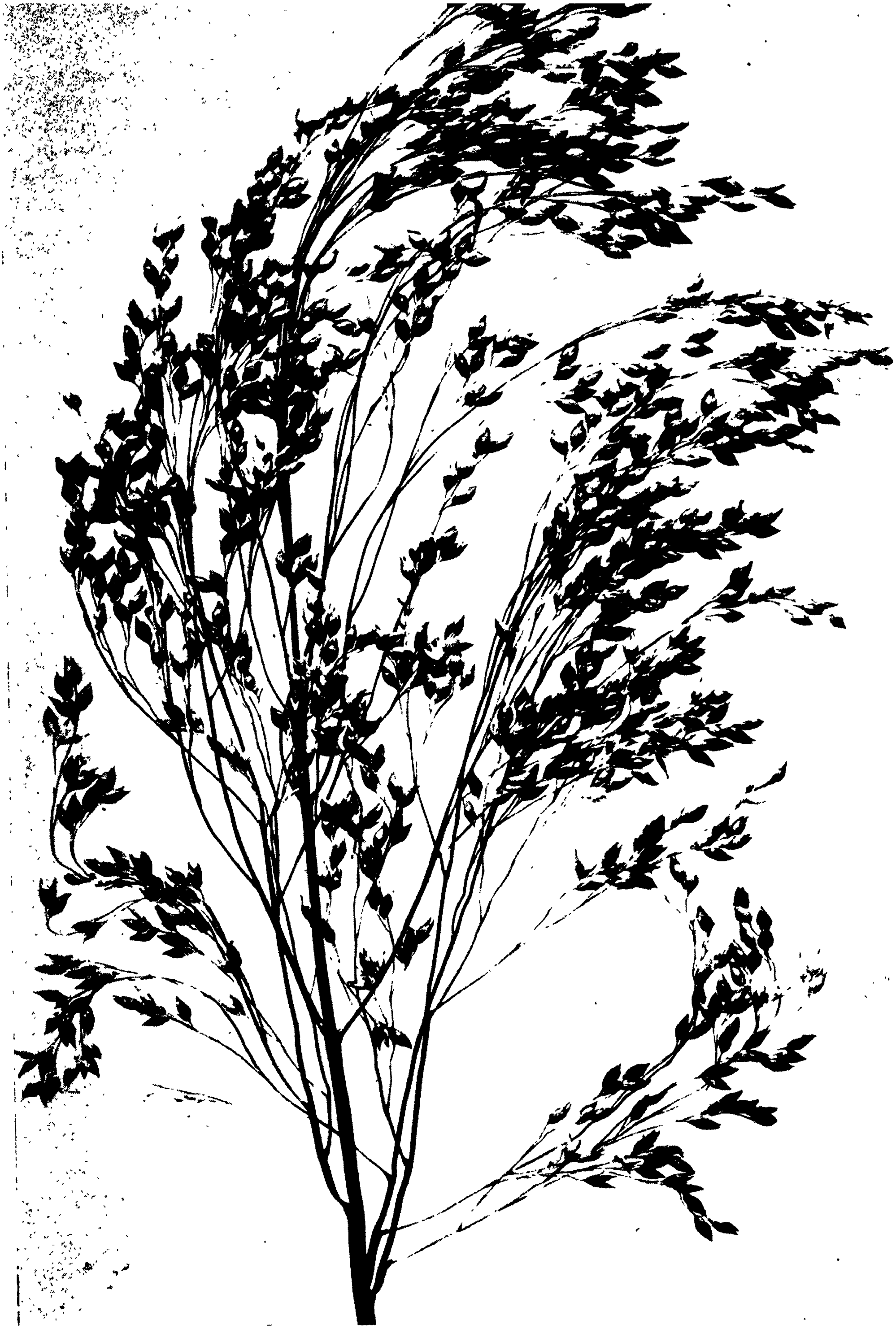

FIG. 2. The open tree-like panicles of Turghai proso, a variety of *Panicum milliaceum* and constituting one of the many forms of millet.

reach China until the 13th century A.D. In recent times sorghum apparently has resisted, better than millet, replacement by other crops. In some areas it has made gains, sometimes at the expense of millet. In India and Manchuria production of sorghum has been greatly expanded in recent years.

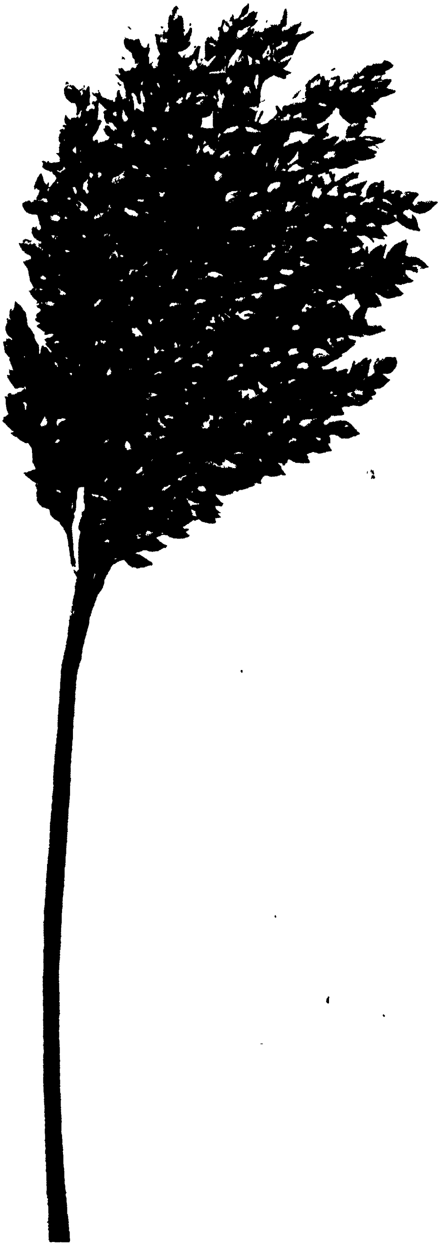

FIG. 3. The compact panicle of Early Fortune proso, another variety of *Panicum milliaceum.*

Some Botanical Aspects

Although millets and sorghums are distinct crops and are so recognized by the natives of Asia and Africa, they are often confused in the minds of Europeans. Thus the British introduced the term "millet" to India where now all of the sorghums and millets are grouped as millets by agricultural authorities. In Australia broomcorn, a sorghum, is called "broom millet". A small-seeded sorghum introduced into the West Indies from Africa during the days of slave importation is still grown there under the French name "petit mil" (little millet). In Germany the millets and sorghums bear the name "Hirse" with various prefixes to indicate the particular kind. The sorghums (kaoliangs) of China have often been referred to by English-speaking peoples as "tall millet". Even in the United States one variety of sweet sorghum is named "African millet".

Millets and sorghums have certain characertistics in common. They are all annual, warm weather grasses; are short-day plants, *i.e.,* are stimulated into early flowering by short photoperiods; and sorghum and at least some of the millets are nitropositive, *i.e.,* stimulated to early flowering by ample available nitrogen. Both sorghums and millets have much smaller seeds in proportion to the size of the mature plant than do the small grains and maize. This results in relatively smaller seedlings and consequently seemingly slower growth until the young plants attain some size. Then the growth curve rises sharply. Another characteristic in common is that in germinating, sorghum and at least some of the millets produce only a single seminal root instead of three or more, as in corn and the small grains. The young plants of both sorghum and millet contain toxic quantities of prussic acid under certain conditions.

Morphologically and taxonomically, millets and sorghums are quite distinct. The sorghums are all members of one genus (*Sorghum*) in one tribe (Andropogoneae) of the grass family, whereas the millets include several genera in two tribes (Chlorideae, finger millet; Paniceae, other millets). Most millets except pearl millet usually range from one to four feet in height. Sorghums may be as short as two feet or as tall as 20 feet. Sorghum is not described in detail here because of an excellent recent article on the genus in this journal[3]. Sorghums include grain sorghum with dry or non-sweet stalks; sorgo or sweet sorghum with abundant sweet juice, grown for forage, sirup, or for "chewing"; broomcorn, grown for its long brush fibers; and Sudan grass and other grass sorghums grown for hay and pasture.

The seeds of some sorghums have a "waxy or glutinous" endósperm, containing only a particular type of branched chain starch called "amylopectin". These varieties are used for making special food delicacies in Asia, and on a small scale for foods, adhesives and industrial products in the United States. Certain varieties of the proso type of millet also have glutinous seeds.

Kinds of Millet

Nearly all grasses, except the common cereal crops of which the seeds have been used for food, sometimes have been called millets. Those most properly regarded as millets belong to six genera: *Panicum*, *Setaria*, *Echinochloa*, *Eleusine*, *Pennisetum* and *Paspalum*. The principal millet species of the large *Panicum* genus are proso (*P. miliaceum* L.), also called "broomcorn millet", "hog millet" and "Hershey millet"; little millet of India (*P. miliare* Lam.); and browntop millet (*P. ramosum* L.) which is sown for feed-

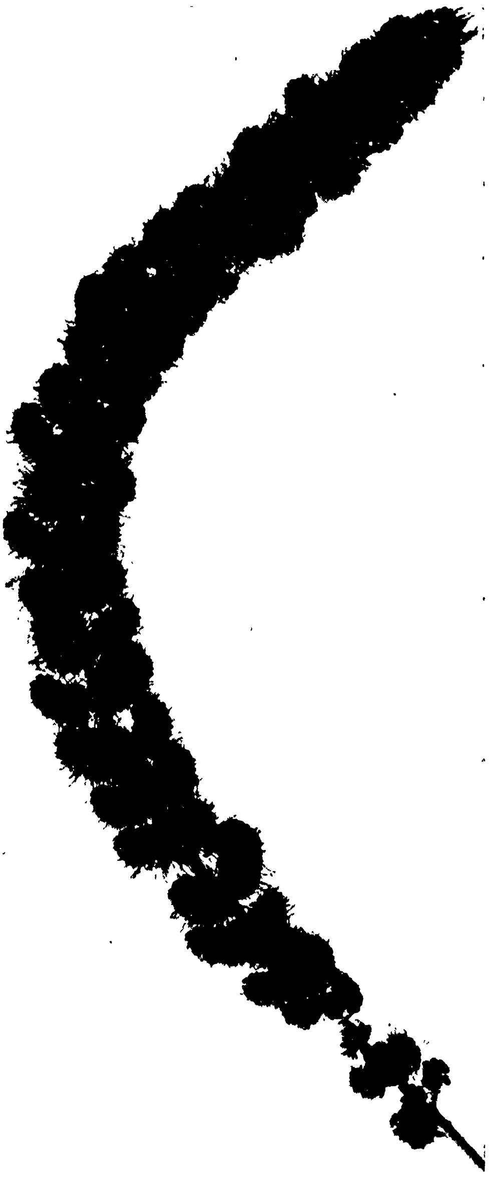

FIG. 4. The spike of Ainu (foxtail) millet, a variety of *Setaria italica*, cultivated by the aborigines of Japan.

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[3] Karper, R. E. and Quinby, J. R., "Sorghum—Its Production, Utilization and Breeding," Economic Botany 1 (4): 355–371. 1947.

ing game birds in southeastern United States.

Pasture and hay grasses of the genus *Panicum* include switchgrass (*P. virgatum* L.), widely distributed in the United States; vine-mesquite (*P. obtusum* H.B.K.) and Texas millet (*P. texanum* Buck.) of the southwestern States; Guinea grass (*P. maximum* Jacq.) of Africa; and Para grass (*P. purpurascens* Raddi) of Africa, tropical America and southeastern United States. The seeds of several other species of *Panicum* are gathered for food in India.

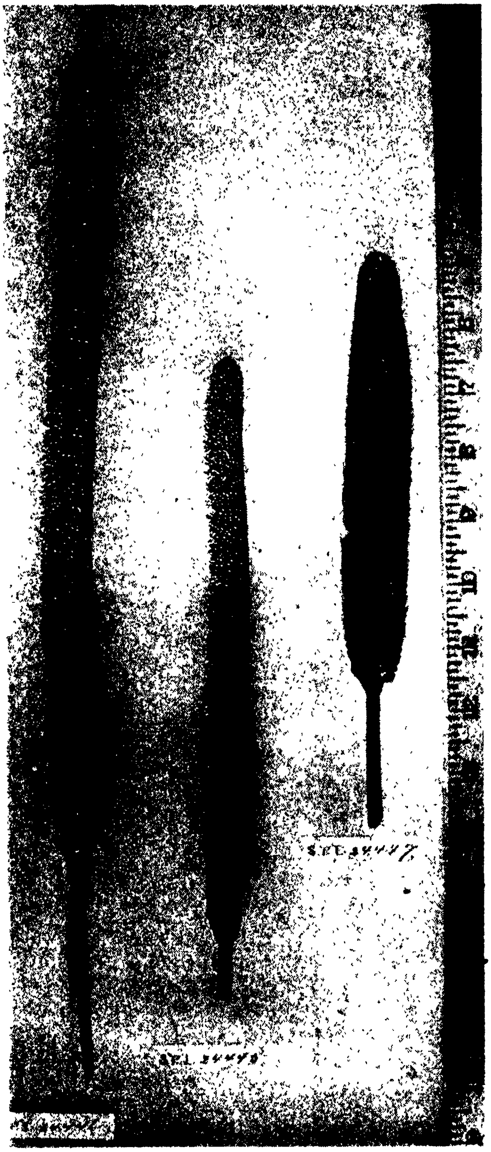


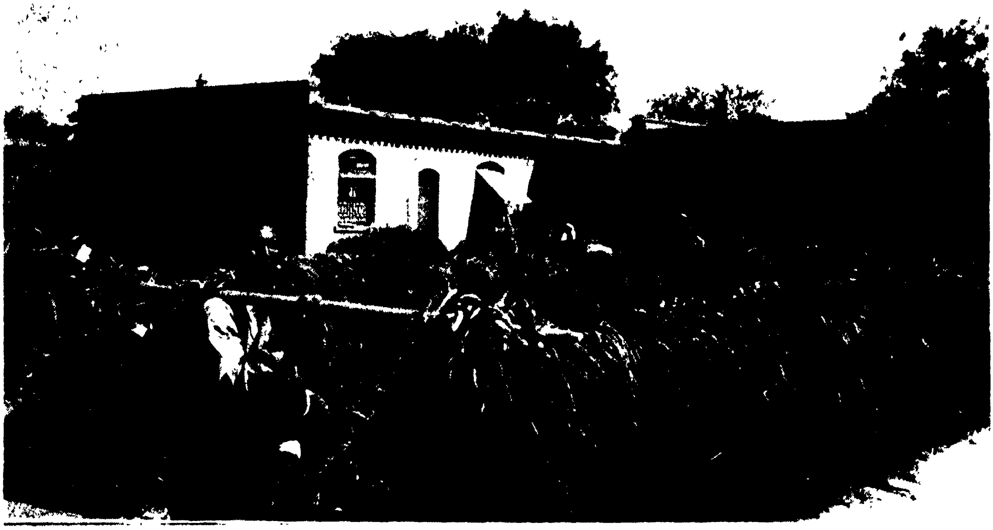
FIG. 5. Spikes of pearl millet, *Pennisetum glaucum*.

Millets of the genus *Panicum* are one to four feet in height, have rather open panicles, and the seeds are slightly flattened. The seeds of proso, which thresh out enclosed in the hulls or glumes, are about 1/10 inch in length. The chaff or glumes of different varieties may be white, cream, yellow, orange, red, gray, green, brown and nearly black. The hulled seed is creamy in color. Some varieties have erect, open, tree-shaped panicles; others have erect, short-branched, compact panicles; while still others have long-branched, nodding panicles. The principal varieties of proso in the United States are Yellow Manitoba, Turghai, Early Fortune, Red Russian, Hansen White Siberian and White French. Hundreds of varieties are grown in other parts of the world.

Foxtail millet (*Setaria italica* (L.) Beauv.) includes such varieties as Common, Hungarian, German or Golden, White Wonder, Siberian and Kursk, grown in the United States. Numerous varieties are grown in China, Manchuria and Russia. The plants are one to four feet in height. The seed is borne in bristly cylindrical spikes which range in length from two to 12 inches. The seeds are more slender and somewhat shorter than those of proso. The hulls which enclose the threshed seed may be yellow, orange, green or gray. The hulled seed is of a creamy color.

Japanese Barnyard millet (*Echinochloa crusgalli frumentacea* (Roxb.) Wight), formerly exploited as "Billion Dollar grass", differs from the grassy weed barnyard grass (*Echinochloa crusgalli* (L.) Beauv.) in having awnless spikelets borne in thick appressed racemes. It is usually three to four feet tall. The spikelets are concave on one side and are borne on one side of each branch of the rather compact panicles. A related species, *Echinochloa colonum* (L.) Link, is the Shama millet or Jungle rice of India.

Finger millet (*Eleusine coracana* (L.) Gaertn.), also called "ragi", "birds-foot millet", "coracan millet" and "African millet", is cultivated for food in Africa and southern Asia. The plants are two to four feet in height. The spikelets are borne in two rows along one side of the



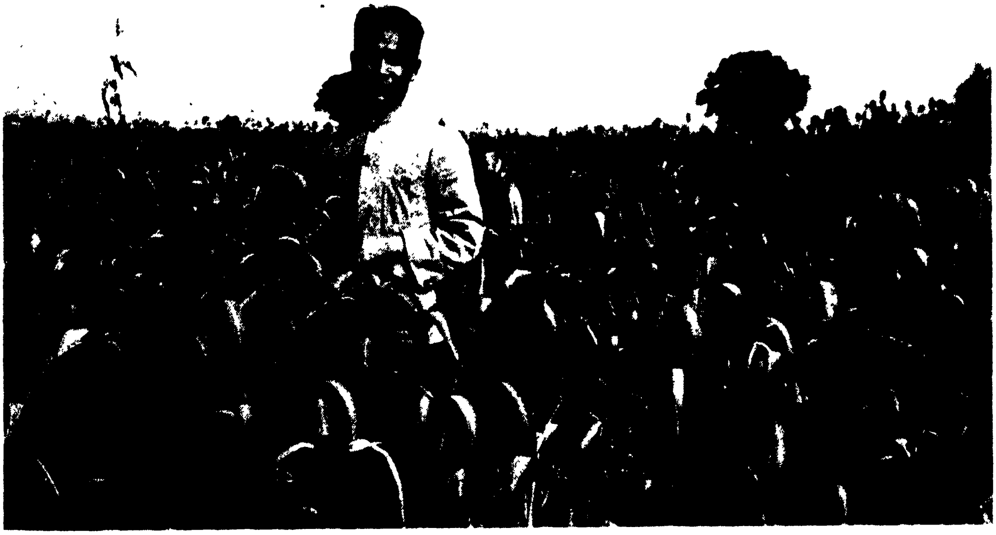


FIG. 6 (*Upper*). A good crop of foxtail millet (*Setaria italica*) drying somewhere in China, previous to the heads being detached and threshed, and the stalks stored for thorough drying.

FIG. 7 (*Lower*). Foxtail millet growing in semi-arid North China where it is an important crop, providing human food and forage for work animals. (*Photos by courtesy of R. T. Moyer, U. S. Dept. Agr., Off. For. Agr. Rel.*).

rachis of the spike. The two to several spikes, or "fingers", arise at the top of the stem. The straw-colored chaff encloses small white seeds.

Pearl or cattail millet (*Pennisetum glaucum* (L.) R. Br.) is the crop known as "bajra" or "bajri" in India. This large grass plant has stems that range up to ten feet or more in height and an inch in thickness. The stiff cylindric head or spike of pearl millet usually is from eight to 18 inches long and about one inch thick. The heads are similar in size and shape to those of the common cattail found growing in shallow waters, but they have a beaded appearance resulting from the exposed pearly-white seeds. The seeds, which thresh out free from the hulls, are much larger than those of any other millets. Most of the seeds of other millets remain in the hulls during threshing. Pearl millet is related to the perennial Napier grass (*P. purpureum* Schum.), introduced into southeastern United States in 1913.

The koda millet of India, or Ditch millet of New Zealand (*Paspalum serobiculatum* L.), resembles certain forage grasses of the genus *Paspalum* that are grown in southeastern United States, including Dallis grass, Vasey grass and Bahia grass. The seeds are borne in two rows on one side of the rachis of spike-like racemes.

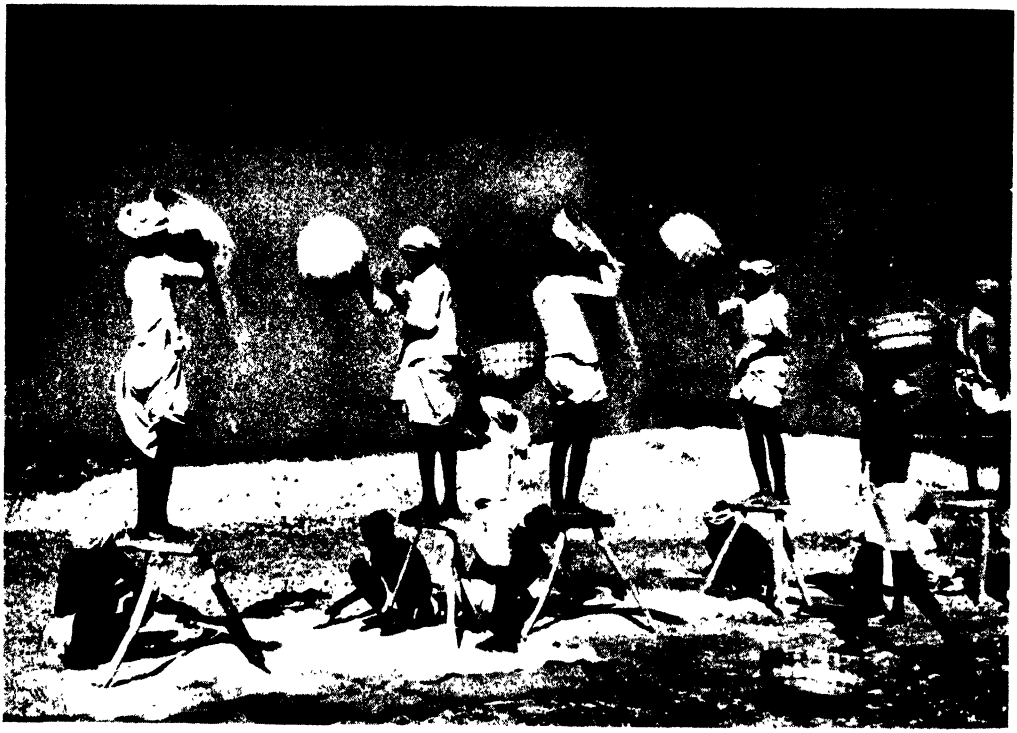


FIG. 8. Winnowing threshed pearl millet, *Pennisetum glaucum*, in India.

Environmental Requirements for Millet and Sorghum

Perhaps the main reason for the survival of millet and sorghum as important food grains in large sections of the earth is that most varieties produce, under conditions of intense heat and scanty rainfall, a greater quantity of grain than other cereals produce. Sorghum can remain dormant during a drought and then resume growth when rains come. On the other hand, sorghum also thrives and produces much higher yields under irrigated or high rainfall conditions. Most varieties of millet have the additional advantage that they require only a short growing season. In India, where much depends on when the monsoon arrives, millet is very valuable. If the monsoon comes too late for other spring grains, millet may be planted, and it is almost sure to produce some kind of crop. It is also valuable as a second or catch crop. Another advantage is that seed requirements are low, since the seeds are relatively small. This is important in countries like India and China where many poor people live on the land. Many of them find it difficult to save the grain required for the next season's seeding.

Cattail millet makes a minimum claim on soil, but it requires hot weather. It grows in a dry light soil and thrives on plains that have extended dry periods, such as western Ghats and the plains of Rajputana in India, and in the Sudan near the Sahara. In the United States it is confined largely to the humid areas of the Southeast.

Finger millet is a hardy plant that grows in almost any soil. In contrast with other millets it thrives in a moist climate but does not do well where there are very heavy rains. It grows at an altitude of 6,000 to 7,000 feet on rocky soil in the rainy foothills of the Himalayas.

Proso grows farther north than any other millet. It thrives in southern and central Russia, central Europe, northern India, northern China and Manchuria. It grows very fast and needs relatively little water, but it demands better soil than the millets listed above. It is especially suited to a dry continental climate, such as that of central Asia.

Foxtail millet needs fair soil and moderate temperatures.

Barnyard millet is grown chiefly in Japan. It is adapted to temperate, humid and sub-humid conditions. A relative is the guinea grass, a native of tropical Africa, which grows eight feet tall and yields a nutritious grain.

Production and Consumption[4]

It is difficult to obtain reliable statistics for millet and sorghum because they are grown and consumed principally in Asiatic and African countries where crop reporting has not been developed so well as in Europe and America, and because they do not enter into international trade to any extent. For instance, in India where statistics for most crops are fairly reliable, a large part of the millet and sorghum is grown in the native States where crop statistics are far from complete. In compiling the accompanying tables, official statistics have been used for those countries which publish official figures; when these were not available, unofficial estimates have been included. However, in large areas in Asia and Africa some millet and sorghum are grown and consumed, but no statistics are available. Therefore, the estimates of total production and con-

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[4] Many persons in the Department of Agriculture were consulted by Miss Anderson in the preparation of her part of the manuscript, especially O. C. Stine, Assistant Chief, Bureau of Agricultural Economics; H. L. Shantz, Collaborator, Forest Service; Raymond T. Moyer, Naum Jasny, and other members of the Office of Foreign Agricultural Relations; Carleton R. Ball, collaborator, Extension Service; Bernice K. Watt and Annabel L. Merrill, Bureau of Human Nutrition and Home Economics; Charlotte Chatfield, Office of Marketing Services; Louise Stanley, Agricultural Research Administration; and George C. Edler and Thomas J. Kuzelka, Bureau of Agricultural Economics. J. Lossing Buck, writer on Chinese Agriculture, read the manuscript, offered suggestions and expressed satisfaction that the subject of millet and sorghum is receiving attention because of its importance as a food for many people of the world.

TABLE 1

MILLET (GRAIN): PRODUCTION, TRADE AND CONSUMPTION, BY COUNTRIES, AVERAGE 1934–38.

Country	Production	Imports	Exports	Seed and waste	Consumption		
					For feed	For food	
						Total	Per capita
	Short tons	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Pounds*
Asia:							
China	8,867,000[1]	13,840	26,335	620,000	708,000	7,527,000[2]	36
Japan	175,324	9,225[3]	...	22,000	70,000	93,000	3
Korea	693,120[4]	161,096[5]	...	106,000	...	748,000	66
India	5,720,282	434	5,330	572,000	286,000	4,857,000	27
Manchuria	3,206,686	...	176,991	212,000	212,000	2,606,000	135
Turkey	48,760	...	6,969[3]	650	10,450	30,700	4
Africa:							
French Equatorial Africa	435,408[6]	...	...	44,000	...	391,000	223
Algeria	267	4,747	269	30	...	4,700	1
Belgian Congo	19,857[6]	...	...	2,000	...	18,000	4
Cameroon	319,667[3]	...	.	32,000	...	288,000	229
Egypt	469,090	4	3,398[3]	46,400	...	419,300	51
French W. Africa	2,243,548[7]	31[8]	848[7]	224,300	...	2,018,400	270
French Morocco	7,958	543[4, 7]	3,214[7]	480	...	4,800	1
Kenya	131,701[6]	177[9]	26[9]	13,400	...	118,500	70
Madagascar	618[3]	10[7]	...	60	...	570	[10]
Tanganyika	321,706[6]	...	211[3]	32,200	...	289,300	110
Uganda	155,308[6]	59[9]	8[9]	15,500	...	139,900	75
Nyasaland	231	...	...	20	...	210	[10]
So. Rhodesia	11,706[11]	...	...	1,200	...	10,500	15
Europe:							
Bulgaria	8,095	...	1,466	850	2,000	3,800	1
Austria	6,995[3]	517[12]	4[3, 13]	700	6,800	...	...
Czechoslovakia	3,097	6,819		400	9,500	...	...
France	10,039	18,000[14]	400	1,200	24,000	2,400	[10]
Greece	1,845	129[15]	34[15]	200	875	865	[10]
Hungary	8,543	256[4]	1,959	800	5,500	500	[10]
Poland	113,655	...		11,000	1,000	101,700	6
Rumania	41,546	...	6,725[7]	3,500	27,300	4,000	[10]
U.S.S.R.	3,033,155	...	1,801[7]	303,100	136,000	2,592,000	30
Spain	4,582[4]	107[4, 16]	.	450	2,100	2,100	[10]
Yugoslavia	29,240	4[3]	1,039	2,410	25,400	400	[10]
Australia:	544[3]	78[4]	57	60	505	...	...
South America:							
Argentina	60,186[6]	...	26,947	6,000	...	27,000	4
North America:							
United States	15,000	2,621	.	1,500	16,000	...	...
Total	26,164,759	218,697	264,031	2,276,410	1,543,430	22,299,645[17]	

TABLE 1

Production estimates for China from the Statistical Abstract of China, 1940; for Manchuria, from 6th Report on Progress in Manchuria to 1939 (So. Machurian Railway Co.). Estimates for British India and Burma from Estimates of Area and Yield of the Principal Crops in India, Vol. I and Vol. II, combined with estimates for the Indian States calculated from the reported area estimates. Estimates for the Belgian Congo, Kenya, Tanganyika, Nyasaland, Southern Rhodesia and Uganda calculated from acreage estimates by H. L. Shantz in Economic Geography, June, 1940. Estimates for Korea from cable by O. L. Dawson, Agricultural Attaché, Shanghai, February 15, 1939; U.S.S.R., from official publications. All others from International Institute of Agriculture. Consumption for China based on percentage distribution of crops for different uses from China Crop Report of the National Agricultural Research Bureau of Nanking, Vol. VI, No.

sumption given here are conservative, and actual production and consumption may be considerably larger. Tables 1 and 2 summarize the information that is available concerning world production and consumption of millet and sorghum.

About 90 percent of the world's crop of millet and sorghum is grown in China, India, Manchuria, French West Africa and the Soviet Union; China and India together produce about 60 percent. World production of millet is somewhat larger than the production of sorghum, and is more widely diffused. Of the millet crop 88 percent is grown in the five countries listed, whereas 90 percent of the sorghum crop is grown in the first four (Tables 1 and 2).

It is estimated that average world consumption of millet for food during the period 1934–1938, was 22,300,000 short tons, or 85 percent of the total crop. About six percent, or 1,500,000 short tons, was fed to livestock and fowls. A smaller proportion of the sorghum crop was used as food, about 18,100,000 short tons, or 75 percent, and consumption as feed was about 3,900,000 short tons, or 16 percent.

Where Grown

China. Millet and sorghum are staple foods in China, and they are grown there extensively. It is generally believed that the Chinese live on rice, but it is only in southern China that rice is the principal food of the people. In northern China wheat, millet and sorghum are the staples.

Sorghum is grown in many parts of China and is called "kaoliang" which means, literally, "high grain". In the central and western sections of China it is known as "shu-shu". It is estimated that 45 to 55 percent of koaliang grain utilized on farms is used for foods, and about 20 percent for feed. Some of the grain is used in making wine and some for brandy. Kaoliang stalks, which often grow 10 to 12 feet tall, are used in a variety of ways—for building fences and bridges, the walls, partitions and roofs of farm buildings, for weaving mats and baskets, and making paper, fibers and brooms. In some parts of China there is little or no wood or coal, and large quantities of kaoliang stubble are used for fuel.

Kaoliang grain is ground into flour and groats which are consumed as bread or porridge. The well-to-do use kaoliang mixed with a large percentage of wheat flour for bread-making. Alcoholic drinks made from kaoliang are favorites among the Chinese people.

Although kaoliang is grown over most

10, October 1938. For the U.S.S.R., consumption was calculated on the basis of percentages reported officially. For all other countries, consumption is production less net exports, less seed and waste; estimates of seed and waste, feed and food made on the basis of unofficial estimates and information received from members of the Office of Foreign Agricultural Relations.

[1] 1934–37 average. The estimate for 1938 is incomplete because of war conditions.

[2] Includes 880,000 short tons for "other uses" such as alcoholic drinks.

[3] 4-year average.

[4] 2-year average.

[5] Imports from Manchukuo and China only.

[6] Estimate for 1 year only.

[7] 3-year average.

[8] Imports from Algeria and France only.

[9] Estimated from trade figures for Kenya and Uganda.

[10] Less than 0.5 pounds.

[11] Half of the amount estimated for millet and sorghum.

[12] Imports from Manchukuo, Egypt, and Yugoslavia only.

[13] Exports to Germany, Yugoslavia, and Czechoslovakia only.

[14] Half of imports of dari, millet, and alpiste, which are not reported separately.

[15] 1930–35 average imports or exports.

[16] Imports from France only.

[17] Cross total will not check due to rounding.

TABLE 2

SORGHUM (GRAIN): PRODUCTION, TRADE AND CONSUMPTION, BY COUNTRIES, AVERAGE 1934–38

Country	Production	Imports	Exports	Seed and waste	Consumption		
					For feed	For food	
						Total	Per capita
	Short tons	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Pounds*
Asia:							
China	7,648,000[1]	...	4,812	535,000	1,529,000	5,579,000[2]	27
Burma	67,872	...	17[3]	6,800	3,400	57,700	7
India	7,540,236	434[4]	5,330[4]	754,000	377,000	6,404,000	35
Manchuria	4,420,393	...	176,916	297,000	636,000	3,310,000	171
Syria and Lebanon	68,734	...	...	6,900	30,900	30,900	17
Africa:							
Algeria	5,766[3]	...	...	600	...	5,200	1
Belgian Congo	13,608[5]	...	...	1,500		12,000	2
Anglo-Egyptian Sudan	376,488[5]	...	...	37,600	...	338,900	110
French W. Africa	2,180,000[6]	...	...	211,500	...	1,968,500	263
Dahomey	1,000,000	...	...	100,000	...	900,000	
Ivory Coast	245,000	...	...	25,000	...	220,000	
Senegal	650,000		...	58,000	...	592,000	
Other	285,000	...	...	28,500	...	256,500	
French Morocco	40,065[3]	...	1,480[3]	3,900	...	34,700	11
Tunisia	3,031[6]	...		300	...	2,700	2
Uganda	50,085[2]	...	...	5,000	...	45,000	24
Kenya	50,000	...	...	4,000	...	46,000	27
Union of S. Africa	116,747[7]	...	323	12,600		103,800	21
So. Rhodesia	11,706[8]	...		1,200	...	10,500	15
Europe:							
U.S.S.R.	160,000	...	...	15,000	35,000	110,000	1
Hungary	21,423			2,500	9,500	9,400	2
Rumania	25,373	...	6,725[3]	2,000	15,700	900	[9]
Spain	823[10]	...		100	600	100	
Yugoslavia	3,568	...	2,700	90	710	100	
South America:							
Uruguay	404[11]	...	...	40	360	...	
North America:							
United States	1,367,783	...	...	140,000	1,227,783	...	
Total	24,172,105	434	198,303	2,037,630	3,865,953	18,069,400[12]	

TABLE 2

Production estimates for the United States from reports of the Crop Reporting Board, United States Department of Agriculture; for China, from the Statistical Abstract of China, 1940; for Manchuria, from 6th Report on Progress in Manchuria to 1939 (So. Manchurian Railway Co.). Estimates for British India and Burma from Estimates of Area and Yield of the Principal Crops in India, Vol. 1 and Vol. 2, combined with estimates for the Indian States calculated from the reported area estimates. Estimates for the Belgian Congo, Anglo-Egyptian Sudan and Uganda calculated from acreage estimated by H. L. Shantz in Economic Geography, June, 1940; all others from International Institute of Agriculture. Trade figures from official publications. Consumption for China based on percentage distribution of crops for different uses from China Crop Report of the National Agricultural Research Bureau, Vol. 6, No. 10, October 1938. For the United States, consumption for feed is production minus seed requirements. Consumption for all other countries is production less net exports less seed and waste; estimates of seed and waste, feed, and food were made on the basis of unofficial estimates and information received from members of the Office of Foreign Agricultural Relations.

[1] 1934–37 average. The estimate for 1938 is incomplete because of war conditions.

of central, west and north China, and in Manchuria, the chief producing provinces are Shantung, Honan and Hopei, where about 60 percent of the crop is produced. In some parts of China where the climate is favorable, two or three crops are grown each year. One crop is kaoliang or some kind of millet, depending on the rainfall. Kaoliang is grown extensively in southern Manchuria, although in recent years soybeans have crowded it out in many areas. In southern Manchuria millet is planted in May. A furrow is made in each middle between rows of the previous year and a man following the plow, drops seed from a gourd-kaoliang stalk planter. Soil is kicked into the furrow to cover the seed and then compacted with an oval stone roller drawn by a donkey. The harvested millet is placed on the threshing floor or ground with the heads toward the center and then threshed with stone rollers. It is used as flour for bread and cakes, or as paste from pounded soaked seed, or as boiled gruel. Acreage of wheat has increased, but kaoliang remains an important food of the people. In certain sections, such as northern Hopei, kaoliang is grown extensively. The leaves are used for green feed, the grain for food, feed for animals, and for making alcoholic drinks.

The kinds of millet cultivated in China are mainly foxtail millet, proso and finger millet, but no cattail millet. Foxtail millet, by far the most important, is grown in Hopei, Shantung, Honan and Shansi, and in north China generally. This hardy plant, which grows in many regions where other cereals do not thrive, is found in the mountainous sections as well as on the plains of many parts of China. Proso is grown principally in Shantung, Hopei, Shansi and Kansu. Sometimes it is used in making a kind of wine. Finger millet is grown mainly in Shantung, Shansi and Szechwan, but not extensively. It is often used for beer making for which it is well suited.

India. Millet and sorghum are among India's chief food crops; about 20 percent of the cropland is devoted to their cultivation. Production of all millet and sorghum averaged 13,260,000 short tons in the period 1934–1938, compared with 10,980,000 short tons of wheat and 28,533,000 short tons of rice. Large quantities of wheat and rice were exported, but practically none of the millet and sorghum. These are consumed within the country, mostly as food. They are staple foods of a large part of the population of India. The stalks, straw and some of the grain furnish feed for animals and fowls.

The official statistics of acreage and production of millet and sorghum for India include only estimates for sorghum ("jowar" or "cholam"), cattail millet ("bajra") and finger millet ("ragi"), which are the principal varieties grown. Several other millets are grown, but there are no acreage and production estimates for them. Jowar is the most important of the three crops mentioned above, the production averaging 7,540,000 short tons for the years

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[2] Includes 2,200,000 short tons for "other uses" such as alcoholic drinks.
[3] 3-year average.
[4] Half of the figure for jowar and bajra.
[5] Estimate for 1 year only.
[6] Rough unofficial estimate.
[7] Half of the amount reported for maize and sorghum.
[8] Half of the amount estimated for millet and sorghum.
[9] Less than 0.5 pounds.
[10] 2-year average.
[11] 4-year average.
[12] Cross total will not check due to rounding.

1934–1938, compared with 3,140,000 short tons of bajra, and 2,580,000 short tons of ragi.

A number of the Indian, or native States report only acreage of sorghum and millet, and others do not report at all, although it is known that some of these States produce one or both crops. Rough estimates of production of both crops have been made for the native States, based on incomplete official acreage estimates for the native States and yields in British India. Although the yields in British India are probably

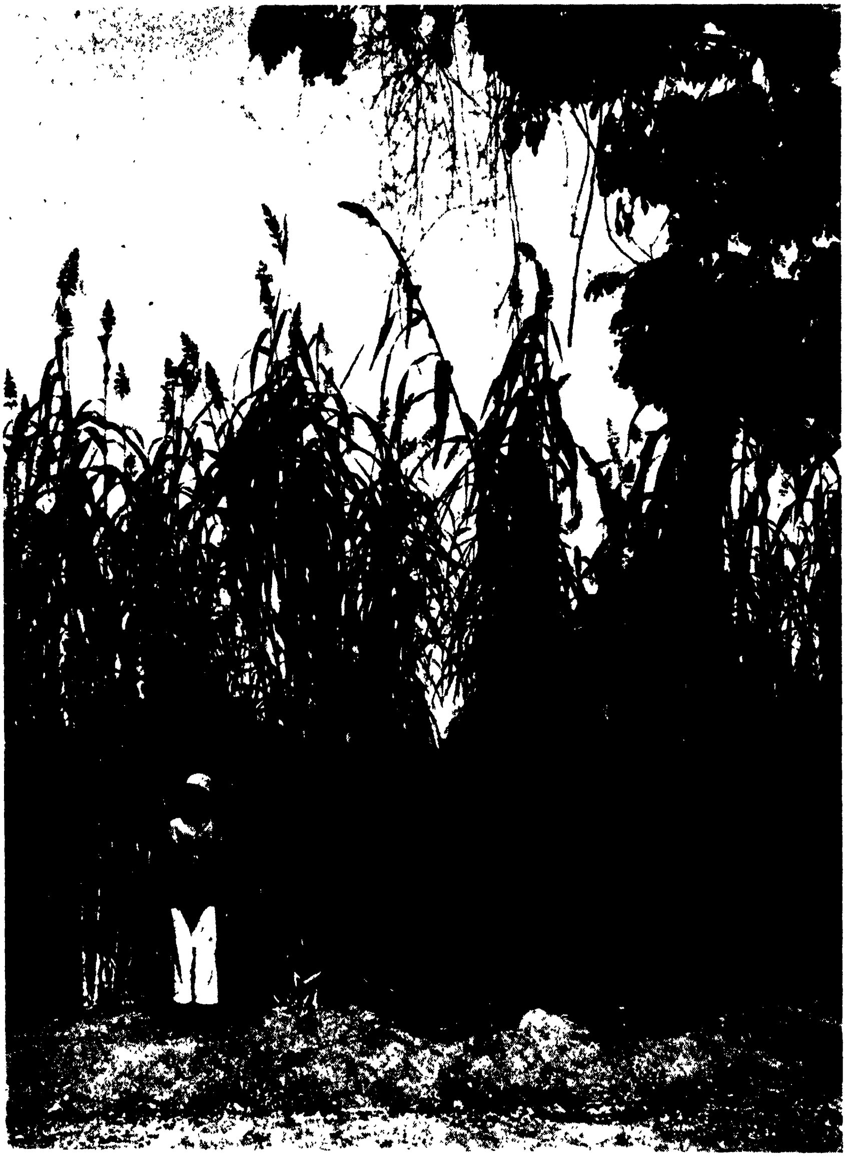


FIG. 9. Irrigated grain sorghum in Ivory Coast, West Africa. (*Photo by courtesy of the Ministère des Colonies, Paris*).

higher than yields in the native States, this is counterbalanced to some extent by the incompleteness of the acreage estimates for the native States. These cereals are staple foods of the people in most of the native States.

Some kind of millet or sorghum is grown in most parts of India,[5] but the principal producing sections are central and southeastern India where the climate is especially suitable. Heavy monsoon rains furnish necessary moisture during the planting season at the beginning of summer, and the lack of moisture in later months does not discourage development of millet and sorghum, whereas wheat and rice do not thrive. If the monsoon is late in arriving, cat-tail millet is substituted for sorghum, provided seed is available, since it can produce some kind of crop with a small amount of moisture. If the monsoon fails entirely, a famine is inevitable. In recent years these famines have been much less severe because of importation of food supplies by the Government.

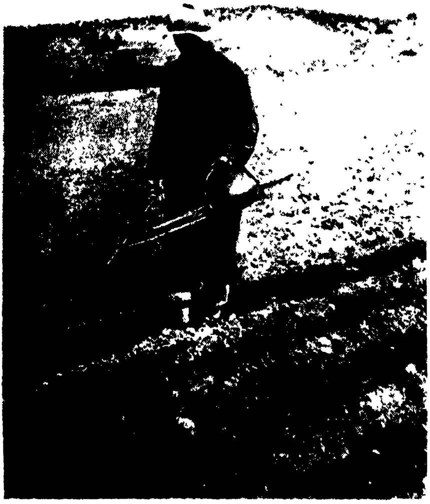
FIG. 10. Sorghum and cotton grown in alternate rows in French Sudan near the Niger river. (*Courtesy of the Ministère des Colonies, Paris*).

Practically all of the sorghum is consumed locally, some of it as animal feed. It is especially valuable to the argicultural population because it yields as much grain per acre as wheat and several times as much fodder.

Sorghum is grown in most parts of India but principally on the Deccan Plateau and in central India, as it resists drought well. About 60 percent of the acreage is in British India and about

[5] An agricultural aphorism from the United Provinces: "The yield is very heavy when sun hemp is sown thickly, jowar at a distance of frogs hopping, and bajra at paces length."

40 percent in the Indian States, according to the statistics published by the Department of Commercial Intelligence and Statistics of India, which are incomplete, especially for the Indian States. The largest acreages in British India are in Bombay, Central Provinces, and Berar, Madras, and the United Provinces. In the Indian States the chief sorghum growing States are Hyderabad, Rajputana and Gwalior. A large sorghum area on the lower banks of the Indus is irrigated, but in most sections the crop is grown without irrigation.



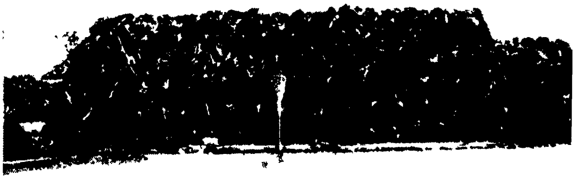


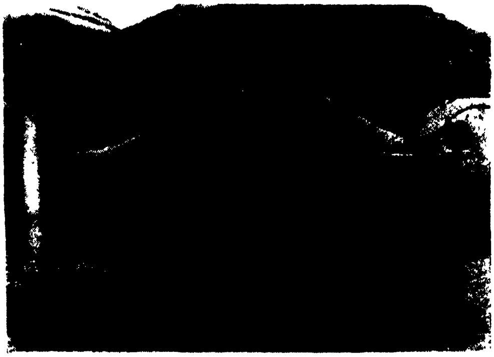
FIG. 11 (*Upper left*). Kaoliang, *Sorghum vulgare* var. *nervosum*, in Manchuria.

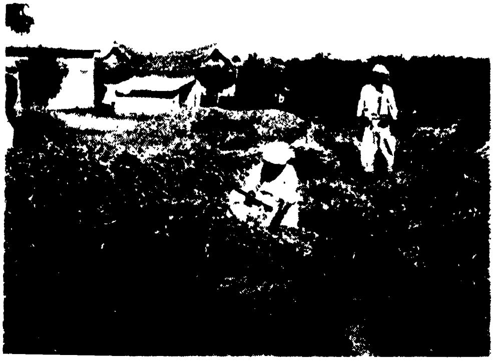
FIG. 12 (*Upper right*). The tunhula, made from a kaoliang stalk and a gourd, is used in Manchuria for sowing millet and kaoliang.

FIG. 13 (*Lower left*). Millet being planted in rows by hand in Manchuria.

FIG. 14 (*Lower right*). A pile of kaoliang heads in Manchuria.

First in importance among the millets of India is cattail millet, or "bajra". No other cereal grows so well in hot dry regions. Most of it is grown in the dry western section where it is the principal food of the people. There are two chief districts for the cultivation of cattail millet, one in Bombay, Rajputana, and the adjoining Ganges plains, the other in the dry section of western Ghats and in Madras. This particular millet thrives better than does sorghum along the lower Indus plains where there is very little rain, but it is not grown farther south along the coast where rainfall is more abundant. It appears as far south as the southern tip of the peninsula where it is sometimes grown as a winter crop.





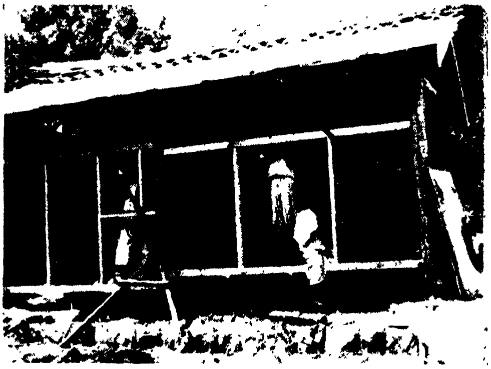


FIG. 15 (*Upper left*). Threshing kaoliang with a stone roller in Manchuria.

FIG. 16 (*Upper right*). Bins of millet in Manchuria made of rice straw, some of the walls plastered with mud.

FIG. 17 (*Lower left*). Women flailing millet in Korea.

FIG. 18 (*Lower right*). Building a house inKorea with woven kaoliang stalks for walls.

Finger millet, or "ragi", next in importance among the millets of India, is grown mainly in southern India where it is used as a bread grain and for making cakes and puddings. More than half of the acreage of finger millet is in Madras and vicinity, and practically all of the remaining acreage is in the native States, mostly Mysore. It appears to thrive in the same climate as does rice and is usually found in India where rice grows. Damp mountain slopes seem to be especially favorable. In some dry sections it is grown under irrigation. It is sometimes sown between the rows of maize which often fails to produce a crop. In this case the millet produces a crop of some sort. Finger millet is seeded following the rainy season, or the seed is sown in May in irrigated beds and the young plants are transplanted to fields at the beginning of the rainy season.

In Gujarat it is grown in alluvial soil and irrigated by flood water, and is often grown as a garden vegetable, in which case the unripe ears are eaten. In the interior, finger millet is planted on the eastern slope of the Ghats and up to the edge of the Deccan plains. On the damp west coast it is supplanted by rice. In south India, in Madras and Mysore, where finger millet occupies two-thirds of the planted acreage, the damp climate is especially favorable for its growth. Sowing and harvesting are dependent on the trade winds. With irrigation a crop may be sown any time of year when water is available.

Although official statistics include only bajra and ragi, many other kinds of millet are grown in India. Foxtail millet is not grown to any great extent, although the natives are very fond of it. The Hindus regard it as a holy food, and it is often prescribed as a food for invalids. It is the principal grain in a small section of the highlands of Mysore where the climate seems to be especially agreeable for it. Most of it is grown as a summer crop. Proso is grown in certain sections, mostly in southern India, south of the Kistna River, where it is one of the principal foods. Other kinds of millet are grown in many parts of India, and although they are important locally, the total production for the country is not large.

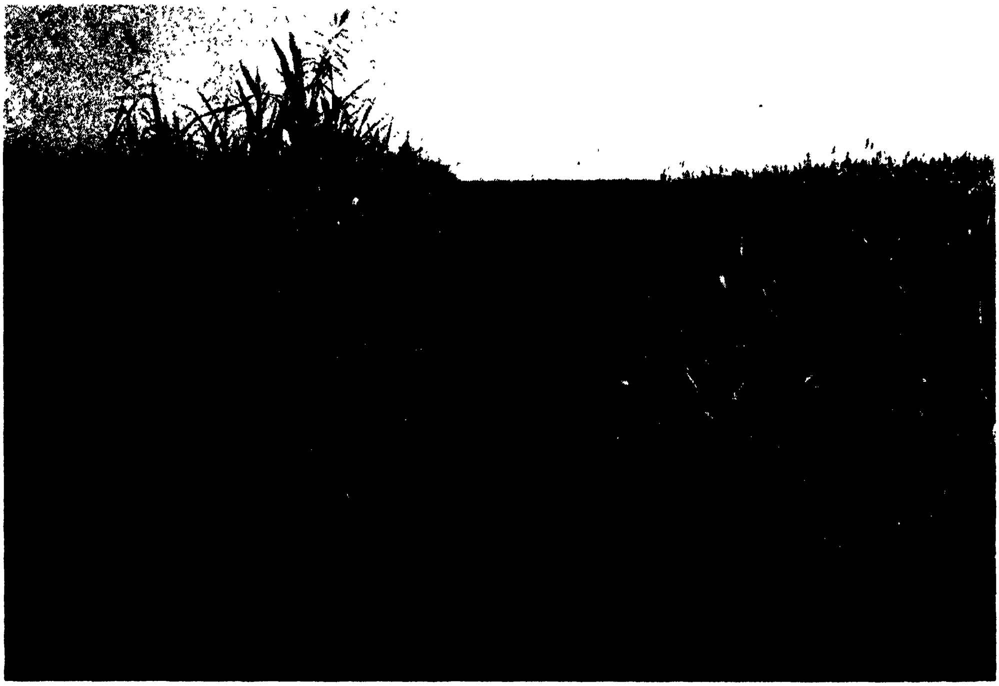


FIG. 19. Sudan grass (*Sorghum vulgare* var. *sudanensis*) (left) and Kursk millet (right), a form of foxtail millet (*Setaria italica*), growing adjacent to one another in South Dakota and showing the difference in size of plants, which accounts for the Sudan grass producing more hay. (*Courtesy of the U. S. Bur. Pl. Ind., Soils, and Agr. Eng.*)

Central Asia and the U.S.S.R. Another chief millet-producing and consuming area is central Asia and Soviet Russia where proso, or bread millet, is widely grown. It is grown in the southern half of Soviet Russia and is a staple food throughout the country. In a broad belt running through central and southern Russia it is one of the important crops. It is eaten mostly in the form of a thick porridge called "kasha". The nomadic peoples, the Mongolians and the Kirgis, are very fond of millet as a food, and as a crop it suits their methods of culture. Many sections have little rainfall but receive water for some type of irrigation from mountain streams. Most of the sorghum production is in the Ukraine, Turkmen and Ufibek, and the acreage is small. In the Ukraine sorghum is used principally as feed for cattle, but in Turkmen and Uzbek it is used mainly for food.

In Arabia, Syria, Iran, Irak and Afghanistan millet has been cultivated for many centuries. Although it is of much less importance today than formerly, a considerable quantity is grown, and it is a staple food of many of the poor people. In Iran, proso, foxtail millet and some cattail millet are grown in the northeastern, southern and western parts, and sorghum grows well in upper Irak. Cattail millet is found in southwestern Arabia, and some sorghum is grown farther north. In Syria sorghum is grown instead of wheat if the rainfall happens to be slight; in Palestine a considerable quantity is harvested.

Africa. Africa has a great sorghum belt running across the continent south of the Sahara from the Atlantic Ocean through French Guinea, the Ivory Coast, Upper Volta, Dahomey, Nigeria, French Equatorial Africa, Belgium Congo, southern Anglo-Egyptian Sudan, Uganda, Ethiopia and British Somaliland. Extensive plantings are found also in Kenya, Tanganyika, northern and southern Rhodesia, and Mozambique. In fact, sorghum is grown in most parts of Africa, but the crop is of less importance in the sections not mentioned. No production statistics are available for many of these countries. Cattail millet and finger millet, often designated as *Pennisetum* and *Eleusine* in literature of Africa, are also grown in many parts of Africa. In most instances, methods of cultivation are extremely primitive.

Sorghum is grown in Morocco, Tunisia and Algeria but not in large quantities. Morocco exports sorghum stalks to Algeria where they are used in the broom industry. Some of the grain is exported to Europe as bird and chicken feed. Millet and sorghum are produced in the oases of the Sahara where a good deal of excellent agricultural land is watered by springs. The grain serves as food for the natives, and the stalks provide fuel and building material. Finger millet is grown in many sections of Ethiopia and Somaliland where it is used for food and for making beer.

Sorghum is the predominant crop of the savannah of the Sudan, and millet is widely grown. In certain sections of the Sudan, cattail millet predominates, and finger millet is the chief crop in other sections where it is the daily food of the people in the form of porridge and beer. Cattail millet thrives in French Equatorial Africa; in Nigeria sorghum yields a rich harvest. In the dry rocky soil near Lake Chad the only crop that does well is cattail millet. Farther south where the soil is better and moisture more plentiful, sorghum reappears. The savannah is well suited to the cultivation of sorghum and corn, and sorghum is again the staple food of the natives as porridge, dumplings and beer. In a dry year when the crop is poor they have porridge but no beer. Also, in a dry year when sorghum does not bring forth a crop, cattail millet may be sown as a second crop, as it requires less rainfall. The climate in tropical East Africa, because of the monsoon rains and dry periods, is favorable for the cultivation of millet and sorghum. In some sections maize is grown, but sorghum is cultivated more generally. In recent years cattail millet and finger millet have not been produced in as large quantities as they were formerly.

In the subtropical Union of South Africa, sorghum is grown in large quantities which are mostly consumed within the country by both natives and whites. The principal food of the natives is sorghum, or "kafir corn", which is eaten after it has been soaked in water. It is also used in making beer and is fed green to livestock. White and yellow grain varieties are used for food, while the red or brown bitter-seeded varieties are used for making beer by all African natives. Thus no hops are needed to furnish the bitterness cherished by beer drinkers everywhere. In Madagascar sorghum is cultivated in the dry western part.

In Egypt, near the Nile, sorghum grows very well, but cotton has crowded it out, except as a second or third crop, which keeps the cotton land well cultivated. Sorghum is grown in Ethiopia and is made into flour for porridge. Finger millet is also grown and is used for porridge and beer-making. The climate of Anglo-Egyptian Sudan is favorable for the cultivation of millet and sorghum which are the most important crops of the savannah. Sorghum, especially, is grown in large quantities and is the staple food of the natives.

Europe. Millet has now little of its former eminence as a cereal grain in Europe except in Soviet Russia where proso millet is grown and used mainly for porridge or for flat bread. In recent years not much has been grown in Europe outside the Soviet Union, Rumania, Poland and Yugoslavia. Small amounts are grown in France, Germany, Bulgaria, Austria, Czechoslovakia and Hungary. In these countries it is used chiefly for feed for animals and fowls, and for making beer.

In Rumania most of the plantings are of cattail millet and are in the Danube plains. It is used mainly for feed, but is still utilized in some localities for bread making. The Bulgarians make a favorite kind of beer from their millet. In Germany millet has almost disappeared. What is grown is proso which is found in southern and eastern Germany. Considerable quantities of cattail millet were grown in France until the end of the last century when production averaged about 575,000 tons, but little is grown now. Small quantities are grown in Spain where in the last century it was a more important grain.

Some sorghum is cultivated in Europe. It is used for food and feed in the Soviet Union and principally for chicken feed in other countries. Broomcorn is grown in Italy, Hungary and France.

United States. The United States consumed about 1,200,000 short tons of sorghum grain as feed and none as food during the period 1934–1938. Sorghum was brought to the United States from Africa and India about the middle of the last century, and during the period 1934–1939 was harvested on about 12 million acres of land, of which four million acres were harvested for grain. The remaining 8 million acres were harvested for fodder and silage, and a little was used for making sirup. Less than 2 percent of the crop is used for making sirup, which is the only food product of any note that was made from sorghum in this country before the recent starch and dextrose factories were established. In the 1890's, and previous to 1920, kafir meal was used as food occasionally in Kansas and other States, especially during a drought.

Most of the sorghum in the United States is produced in the southwestern States, especially Texas, Oklahoma, Kansas and adjacent States, where it has special value because of its resistance to drought and heat. It is grown also on irrigated land in the hot interior valleys of California and Arizona. Sorgo for sirup is grown mostly in the southern States. Broomcorn is grown in Oklahoma, Colorado, New Mexico, Texas, Kansas and Illinois.

Millet is a minor crop in the United States. Roughly about 30,000,000 pounds of seed, mostly proso, are produced, which is used as poultry feed, in birdseed mixtures, as livestock feed and for seed. Proso is grown in North Dakota, South Dakota and Colorado. In general, other cereals yield more grain than does proso in the United States. Foxtail millet is grown for hay in many States but only on a small scale. Barnyard or Japanese millet is grown sparingly for hay in Pennsylvania, New York, Iowa and occasionally elsewhere.

Proso is sown in the United States with a grain drill in late May, June or early July, at the rate of 20 to 40 pounds per acre. It is ready for harvest about 60 to 75 days after seeding, but ripening is not uniform. The seeds in the tips of the earlier heads often are dead ripe and have shattered out before the lower seeds and later panicles are mature. The stems and panicle branches are still green when the seeds ripen. This irregular ripening usually precludes safe harvesting by direct combining. Most of the crop is cut by a swather which permits the crop to cure in windrows on the cut stubble. The crop is then gathered and threshed by a combine with a pickup attachment. Sometimes it is cut with a binder, cured in long slender shocks and then threshed.

Foxtail millet usually is sown as a catch crop in May or June, with a grain drill, at a seeding rate of 15 to 30 pounds per acre. It is cut for hay when the heads are in bloom. The seed crop is harvested with a combine or binder. In western Texas and eastern New Mexico it is usually planted at a rate of about four pounds per acre in cultivated rows three feet or more apart for seed production. Formerly, foxtail millet was an important hay crop in the northern and central States.

Pearl millet may be sown with a drill for hay or pasture or planted in cultivated rows for pasture or silage. It is planted in the spring usually in rows four feet apart at a rate of about four pounds per acre. It is confined chiefly to the southeastern States.

Nutritive Value

The mass of the population in India and China eats the cereal that can be grown locally and cheaply. In India many live mainly on millet and sorghum. In China the cereals consumed by the ordinary people are millet, sorghum, wheat and corn in the north, wheat and rice in the central region, and rice in the south. Much has been written about the insufficiency of certain nutrients in the diets of large segments of the population of China and India, and, in many of these reports, millet and sorghum are classed as "inferior" grains.

Studies of the nutritive value of millet and sorghum as compared with that of other cereal grains show that they are, in general, somewhat lower in protein content than wheat and higher in fat content than wheat and rye. They have a higher protein and fat content than rice (Tables 3, 4, 5). The mineral content of most millets is higher than that of sorghum, wheat, rice and rye, but not of soybeans. Millet has a larger percentage of indigestible fiber than most cereals because the seeds are enclosed in hulls. There is good indication that millet is a rich source of thiamine and might be expected to contain small amounts of other B-vitamins.

Studies of diets in northern China, where millet is a staple food, show a deficiency of thiamine much less frequently than the diets in south China where milled rice is the principal cereal consumed. The milling of rice removes most of its thiamine and accounts for the lack of that vitamin in the diet of the poor in south China. Millet is used as a whole-grain cereal and furnishes thiamine in generous amounts.

On the other hand, certain customs in China improve the nutritive value of the diet. In northern China millet and sorghum are mixed with other cereals or legumes. The proteins of such mixtures show a better balance from the nutri-

TABLE 3

AVERAGE COMPOSITION OF CERTAIN GRAINS AND SOYBEANS

Commodity	Average composition				
	Protein	Fat	Fiber	N-free extract[1]	Mineral matter
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Foxtail millet	12.1	4.1	8.6	60.7	3.6
Proso	11.9	3.4	8.1	63.7	3.3
Japanese millet	10.6	4.9	14.6	54.7	5.0
Milo (grain sorghum)	11.3	2.9	2.2	71.3	1.7
Kaoliang grain	10.5	4.1	1.6	71.8	1.9
Wheat, average all types	13.2	1.9	2.6	69.9	1.9
Rice (rough)	7.9	1.8	9.0	64.9	5.2
Rye	12.6	1.7	2.4	70.9	1.9
Soybeans	37.9	18.0	5.0	24.5	4.6

Compiled from "Feeds and Feeding," by F. B. Morrison, 1948.

[1] Carbohydrate except fiber.

TABLE 4

COMPOSITION OF CERTAIN AFRICAN MILLETS AND SORGHUM

Grain	Water	Crude protein	Ether expressed as fat	Fiber	Carbohydrate (N-free extract)
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Gray millet	11.2	8.2	4.0	1.2	73.4
Pearl millet					
Sample 1, "Mawali"	10.6	12.47	5.0	2.8	67.13
Sample 2	12.67	9.78	3.61	1.98	70.43
Sample 3	9.4	13.7	5.1	2.1	67.7
Finger millet	10.3	5.4	1.5	3.4	76.9
Average	10.83	9.91	3.84	2.30	71.11
Sorghum					
Durra	8.45	13.06	3.3	1.03	72.45
White kafir					
Sample 1	11.93	9.79	3.22	1.27	72.50
Sample 2	8.45	13.06	3.30	1.03	72.45
Sample 3	12.8	9.9	3.4	1.3	71.0
Red kafir					
Sample 1	12.0	10.83	3.37	1.28	71.01
Sample 2	10.0	11.2	2.8	1.8	72.1
Sample 3	13.5	11.1	3.7	1.4	68.9
Mixed kafir	11.73	10.01	3.06	1.14	72.58
Average	11.11	11.12	3.27	1.28	71.62

Compiled from "Food and Nutrition of African Natives," International Institute of African Languages and Cultures, London, Memo XIII, 1937.

TABLE 5

Composition and Fuel Value of Certain Chinese Agricultural Products

Agricultural product	Water	Protein	Fat	Ash	Crude fiber	Carbo-hydrates	Calorie value
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Millet							
Foxtail	10.5	9.7	1.7	1.4	0.1	76.6	361
Foxtail	9.5	9.7	4.2	1.8	0.8	74.0	372
Proso							
Glutinous	8.5	10.9	3.4	1.6	1.0	74.6	372
Glutinous	10.6	9.7	0.9	1.0	0.9	76.9	355
Non-glutinous	15.8	10.5	0.9	1.2	0.9	70.7	333
Finger	8.5	5.8	5.8	3.6	2.0	74.3	373
Kaoliang (grain sorghum)							
Yellow	5.6	9.7	4.1	1.1	1.5	78.0	388
Red	12.1	8.0	4.2	1.3	1.8	72.6	360
"	9.0	9.5	4.7	2.5	1.8	72.5	370
White	13.7	11.9	5.0	3.0	1.6	64.8	352
"	3.7	9.3	5.0	1.5	0.4	80.1	402
Wheat (whole)	10.5	12.4	1.4	2.5	2.4	70.8	345
"	7.8	11.5	1.8	2.8	1.1	75.0	362
Rice (whole)	14.4	9.9	0.9	1.5	0.8	72.5	338
High grade	10.1	9.6	0.2	0.3	0.2	79.6	359
Middle grade	11.0	8.5	0.3	0.6	0.5	79.1	353
Low grade	11.9	7.3	0.4	1.0	0.7	78.7	348
Glutinous	12.4	6.5	0.2	1.1	0.4	79.4	345
Soybeans							
Black							
1. *Glycine max.*	8.4	42.9	12.6	3.9	6.2	26.0	388
2. Large	8.0	51.3	16.6	4.3	3.6	16.2	419
3. Small	7.8	49.8	12.1	4.6	6.8	18.9	384
Green	6.4	37.3	18.3	5.0	3.4	29.6	432
Yellow	8.8	39.2	17.4	5.0	4.2	25.4	415
Cowpeas (*Vigna sinensis*)							
1. Sample 1	10.3	21.3	2.2	3.4	4.3	58.5	339
2. Sample 2	9.1	22.6	2.2	3.5	4.2	58.4	344

Compiled from Analyses of Chinese Food Materials by W. H. Adolph, Philippine Journal of Science, July 1926; and Nutritive Value of Chinese Foods by Hsien Wu, Chinese Journal of Physiology, Report Series 1928, No. 1.

tional standpoint. A recommended mixture is maize, millet and soybeans.[6] The use of sprouted millet also adds nutrients to the Chinese diet. Good as these customs are they do not take care of all of the deficiencies of needed nutrients.

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[6] See William H. Adolph and Fa-Wu Cheng, "The Biological Value of Mixed Cereal Proteins," Chinese Journal of Physiology, August 15, 1935, pp. 245–252.

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Utilization Abstract

Cortisone from Yams. One of the most important recent medical discoveries is that of treating rheumatoid arthritic victims with cortisone, known also as Compound E, an adrenal hormone which is now being obtained synthetically from animal bile. Forty head of cattle are needed to provide the cortisone requirements of one patient for one day, and the cost is now reported to be $5,670 per ounce. Other and less expensive sources of the drug are consequently being sought, and attention is being focussed on plants. The seeds of an African plant, *Strophanthus sarmentosus,* are regarded as providing an unlimited source of raw material for cortisone, and there is now a commission from the U. S. Public Health Service and Department of Agriculture investigating the possibilities of this source in Liberia. The important principle in *Strophanthus* is known as "sarmentogenin" and can be converted into cortisone through 20 steps of conversion, an improvement on the 37 steps needed for cattle bile acid.

A recent discovery has centered attention on tropical American yams, some of which grow in Arizona, New Mexico, Texas and Mexico. From these plants Dr. R. E. Marker, former Professor of Organic Chemistry at Pennsylvania State College, has isolated a material which he has named 'botogenin' and which is looked upon as a possibly very important indigenous and immediately available source of raw material for synthesis of cortisone. (*N. Y. Times, 8/28/49*).

Plant Growth–Regulators

Large-scale use of plant growth-regulating chemicals, unheard of ten years ago, has fostered a multimillion dollar business. In 1948, 27 1/2 million pounds of 2,4-D, once used only in minute doses for laboratory work, were manufactured for agricultural use, primarily in weed eradication. Naphthaleneacetic acid and other compounds are used in smaller but continually increasing quantities in regulating other phases of plant development, wholly apart from nutritional needs supplied by fertilizers.

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Introduction

The list of chemicals finding uses in agriculture has been lengthened considerably in the past few years by the discovery of a variety of synthetic compounds which possess the property of affecting the growth of plants in some way. The uses for these compounds are surprisingly diverse and are being added to constantly as more becomes known about the nature of the responses which they induce. In contrast to the indirect effects of insecticides or fungicides that serve merely to protect from injury, these compounds act directly upon the plant or the crop, but in a different sense to fertilizer materials that supply major or minor nutrient elements. Although not required for growth, they are capable of regulating growth in some part or parts of the plant. The rapid development and widespread adoption of 2,4-dichlorophenoxyacetic acid, or 2,4-D, as a herbicide have perhaps given the impression that this class of substances will find its main outlet in weed eradication or weed control. While it is undoubtedly true that herbicidal uses will be of great importance and perhaps may provide the greatest volume of business to the chemical industry, it is to be emphasized that chemicals possessing plant growth-regulating activity should not be classified only as herbicides, and even as herbicides they have little in common with the contact herbicide of the past.

Responses Induced in Plants by Growth-Regulators

Plant growth-regulators are sometimes referred to as "plant hormones" or "phytohormones". Unlike animal hormones which are highly specific in character and, in general, control a limited set of transformations, the so-called plant hormones have the appearance often of being relatively unspecific and of controlling, initiating or directing a number of superficially unconnected changes.

Most growth-regulators, if applied to plants at sub-lethal or sub-inhibitory levels, may give rise first to curvatures or epinastic responses and later to so-called formative effects or changes in the general morphology or habit of growth of the plant. Terminal growth may cease and axillary bud development be induced so that a low bushy plant results; the stem may thicken and split; leaf modification may appear with changes in shape and patterns of venation; the root system may be altered in character. It is to be noted that responses can be produced either in actively growing tissues or by reactivation in maturer tissues of cells which have already completed their normal growth. In some cases normal differentiation appears to be prevented, and gall tissue or callus tissue may be formed as a result of division and proliferation of cells without subsequent differentiation.

Present Uses of Growth-Regulators

The uses that have been made of growth-regulators to date do not fall into any single pattern. In a general way they can perhaps be put into two categories, though the responses involved are not always sharply separable. In the first category are uses that depend on some inductive or formative effect in the plant. Such applications are usually relatively critical with respect to dosage, but not necessarily specific with respect to the active compound. In the second category are treatments that are primarily inhibitory or even lethal. It is likely that many applications of both types remain to be developed.

Root Initiation. Vegetative propagation of plants has been aided greatly by the finding that root initiation can be induced in cuttings of many species by brief treatment with growth-regulating compounds. Those most widely employed for this purpose are indole-3-butyric acid and alpha-naphthaleneacetic acid or a derivative thereof. Many substituted phenoxyacetic acids have the same property, but as the margin between active root initiation and inhibitory or formative effects in other parts of the plant is much narrower in this group, they are not ordinarily employed. The rooting response is particularly useful in the case of woody and semi-woody species. Not all species, however, can be induced to root by application of compounds currently available; they thus present a challenge to the chemist and physiologist to seek additional substances with this property.

Fruit-setting and Flower Drop. By treatment of some flowers with certain growth-regulators, fruit-set without pollination may be accomplished. The fruit so obtained is seedless. Applications are usually made by aerosol or vapor treatment. Alpha-naphthaleneacetic acid or some derivative is the main choice, though the list of compounds known to induce parthenocarpic fruit development is extensive. Fruit so produced may be larger in size or weight than fruit formed as a result of normal pollination, although undesirable changes in the morphology of the fruits may be encountered if the optimum treatment rates are exceeded. The chemical treatment may also prevent flower drop and ensure fruit development from flowers which have been previously pollinated. This technique has been employed widely by growers raising tomatoes in greenhouses where pollination normally is poor, and it appears possible in this way to overcome also the adverse effects of low night temperatures on fruit setting of early field-grown tomatoes.

Bud Initiation, Inhibition and Stimulation. Certain compounds are capable of inducing development of flower buds and so permit some control of the time of flowering. This has proved successful in pineapple culture. Again, alpha-naphthaleneacetic acid has been the compound mainly employed. Curiously enough, this same compound, as well as its derivatives, is highly effective in inhibiting bud development in many other plants, and they are widely employed for preventing sprouting of potato tubers in storage. On the other hand, chemicals are known which have a bud-stimulating influence, and these are used for forcing dormant buds, for example, in potatoes which are to be planted as seed.

Delaying and Prolonging Flowering. Considerable effort has gone into experimentation on delaying the flowering of fruit trees, such as peach and apple, in order to reduce the likelihood of late frost injury in the spring. The margin between dosages which can delay flower opening and those which induce floral abnormalities is a slim one, however, so that treatments of this type are not yet regarded as safe and have not come into general practice. Experimentation aimed at prolonging the blossoming period of decorative fruit trees also has given promising results.

Fruit Drop. Whereas rooting, fruit setting and bud forcing responses are examples of stimulative effects, the prevention of pre-harvest drop of fruits, a practice now widely favored by orchardists, involves an inhibitory action. Many varieties of apple and other fruit commonly fall from the tree before they reach the degree of ripeness desired or before they can be picked so as to avoid bruising. Suitable chemical treatments can apparently delay the development and separation of the abscission layer of cells which is responsible for fruit fall, without causing appreciable change in the rate of ripening. Alpha-naphthaleneacetic acid or a derivative is ordinarily employed at a very low concentration in dusts or sprays. 2,4-D also is effective on certain species.

Accelerating Ripening of Fruit. The normal metabolic behavior of some fruits and vegetables in storage can be altered by treatment with growth-regulators. The ripening of bananas, for example, is accelerated by exposure to a low concentration of 2,4-D, which might be preferable to ethylene as presently employed.

Weed Eradication. Excelling all other uses in importance to agriculture and to the chemical industry at this time, however, are the remarkable applications of growth-regulators in the herbicide field. The substituted phenoxyacetic acids, of which 2,4-dichlorophenoxyacetic has been most studied, can be employed broadly for weed eradication or vegetation control. Although they are not inherently selective in activity they can be utilized in a selective manner by taking advantage of differences in sensitivity and response among species. Perhaps the most important agronomic development is the control of weed growth in a planted or growing crop, either by spray treatments which inhibit weed growth selectively, or by soil teatments which prevent germination and development of weed seedlings.

Production and Consumption of Growth-Regulators

Considering that experimentation with a view toward utilizing 2,4-D as a herbicide was not initiated until 1943, production and sales of growth-regulating chemicals in the United States have shown a remarkable increase during the past few years. In 1945, the first year in which production was sufficiently large to be reported by the U. S. Tariff Commission, 917,000 lbs. of this compound were manufactured. In 1946 the amounts of 2,4-D and its derivatives had increased to 6,461,000 lbs. and in 1947 to 8,866,000 lbs. For the last quarter of 1948, production of the acid was at the rate of 27,512,000 lbs. annually. The figures for naphthaleneacetic acid in 1945, 1946 and 1947 are 33,000, 12,000 and 14,000 lbs. respectively. Thus in a period of three years plant growth-regulator production has grown to a multimillion dollar business.

No data are available as to the actual end uses of 2,4-D, but it may be presumed that the great bulk of this material is used in weed control on cultivated or pasture land. In 1946 and 1947 sales amounted to 90 per cent of production. If this figure is carried over to 1948 and the further assumption is made that 90 per cent of this amount was applied to agricultural land at an average rate per acre of somewhat less than one pound, one obtains a rough estimate of 25 million acres treated during the year.

Only approximations can be made also for the second largest application of growth-regulators, that of preventing preharvest drop of apples and pears, which appears to account for the bulk of the naphthaleneacetic acid manufactured. In recent years some 2,4-D has been used for this purpose. From the first experimental spraying of four apple trees by the U. S. Department of Agriculture in 1939, about 100,000 acres of orchards were treated in 1945 and probably of the order of 150,000 acres in 1948. It is estimated that in the major fruit-producing areas of the western States, two-thirds of the pear and one-third of the apple trees are sprayed with growth-regulators. On the basis of a probable yield increase of 10 to 15 per cent and a cost of 10 dollars per acre for material and labor, the return from spraying in western orchards may be appoximated at 50 to 60 dollars per acre and at perhaps half as much in the East. A substantial amount of naphthaleneacetic acid is believed to be utilized also in the Hawaiian pineapple industry for control of flowering.

If one thinks of these compounds as plant hormones of extremely high physiological potency, the tonnages manufactured are truly startling. For example, a distinct formative effect can be obtained by application of 0.01 microgram of 2,4-D to a young bean plant, which is a commonly used test object. Applied in this way, two pounds of the chemical would be more than enough to produce a response in every edible-bean plant grown in the United States. Indeed if the total cropland of the United States were planted in beans, 4,000 lbs., or less than 0.02 per cent of the 1948 production of 2,4-D, would suffice to elicit visible effects in the plants. Even killing of all these young plants, which can be accomplished with ten micrograms of growth-regulator by suitable means of application, would require only about one-seventh of the total production.

Many of the most useful applications of growth-regulators in horticulture require only highly diluted solutions, and in consequence the total amount that is likely to be required as these practices are extended is not vast. Agronomic uses in the field of weed control are always likely to constitute a far greater bulk outlet. For example, should pre-emergence soil treatments for corn partially or totally supplant cultivation and be widely adopted, the demand for 2,4-D or related compounds would continue rapidly to increase to a figure several times the present consumption.

Selectivity and Specificity

Although, as already stated, there is little evidence to indicate that the compounds which possess growth-regulatory activity are inherently highly specific and selective in action on particular genera, species or varieties of plants, there is a high degree of probability that many can be used in a selective manner. Selectivity is often more apparent than real and is the resultant of different degrees of susceptibility to a particular concentration or amount of active compound. For example, many of the selective herbicidal uses of 2,4-D involve only a dosage selectivity. Established monocotyledonous plants, particularly the cereals and other grasses, are little affected by top application of growth-regulators of the phenoxyacetic type, whereas many broad-leaved plants at a corresponding stage of growth may be heavily affected. However, germinating seeds and young seedlings of grasses may be highly susceptible. Although there appears to be some major difference in sensitivity between monocotyledonous and dicotyledonous species, there are exceptions and inconsistencies in responses to particular compounds. Whether there is a basic biochemical difference between responsive and unresponsive species is not known. The alternative view, namely, that absorption of these compounds and subsequent transport to young rapidly growing tissues may not be accomplished or may be accomplished only slowly by the unresponsive species, may hold in some cases.

In general, as the tissues and organs of plants age and mature they become increasingly less responsive to applications of growth-regulators, and high dosage rates at a late stage may not achieve what can be accomplished by much lower concentrations at an earlier stage. Some of the inductive or formative applications of growth-regulators exploit the different susceptibilities of tissues or organs. The cells involved in floral development, for example, are physiologically young and highly susceptible, whereas most other tissues at this stage are further advanced and, therefore, not likely to be affected by treatments that can result in profound effects in fruit or seed development. It is probable that advantage will be taken of similar differences in organ and tissue susceptibility to develop many other apparently selective uses for growth-regulators.

Structure and Activity

Information relating the molecular structure of plant growth-regulators to their physiological potency is highly desirable both for its possible value in pointing the way toward new "tailor-made" compounds and also in yielding clues concerning the mode of action of these substances. Many pitfalls, not always clearly recognized, stand in the way of obtaining such information, and despite considerable effort present knowledge is quite fragmentary.

Among the heterogeneous assemblage of compounds embraced by the generic term "plant growth-regulators" are some which are very versatile in activities, being capable of producing several of the types of responses previously outlined. Other compounds appear to possess appreciable activity in only a single physiological effect. Thus in endeavoring to relate structure with activity it is essential to define as clearly as possible the kind of activity under consideration and, in some cases, also the precise technique employed in eliciting and measuring the response.

Comparative tests on extensive series of compounds have been reported from only a few laboratories, and among these there exist numerous instances of contradictory results possibly caused by differences in methods.

Some confusion may have arisen through failure to distinguish between what may be termed "intrinsic activity" and "apparent activity". If it is assumed that growth-regulators are effective by virtue of some biochemical reaction in which they participate, then the intrinsic activity would be a measure of the effectiveness of such participation. In practice, what is actually measured is only the apparent activity, which may be the resultant of various ancillory properties such as absorbability by the plant, solubility of the compound in the plant fluids or protoplasm, transportability of the substance within the plant, and rate of inactivation of the material within the plant. As evidence for this statement may be cited the fact that the magnitude and even the character of response to a particular dosage of growth-regulator may be substantially changed by altering the carrier solvent or the mode of presentation.

Additional handicaps to progress on this subject have been the lack of critical methods for evaluating various types of responses, and the difficulty of expressing certain of these responses quantitatively.

At the present stage of development it appears possible to make two, seemingly contradictory, generalizations. On the one hand, what appears to be the same, or certainly closely similar, effects can be produced by a considerable diversity of structural types of molecules. On the other hand, among isomers, analogs, homologs and derivatives of a particular type, a high degree of specificity is exerted by what may be termed loosely the "fine structure" of the molecule. In some cases, however, the structural specificity exhibited in a particular physiological effect does not appear to hold for other effects.

Relatively few aliphatic compounds have been reported to possess growth-regulatory activity, but this may be a reflection of the greater attention which has been given to cyclic compounds.

The majority of the compounds so far demonstrated to be active may be regarded as derivatives of a relatively small number of parent substances which are for the most part ring-substituted aliphatic acids.

Table I shows in a general manner the kinds of activity exhibited by certain of the better known of these classes of compounds. The ratings are intended merely to be roughly indicative, and many exceptions could be noted. Qualitative as well as quantitative differences in responses do occur and further complicate comparisons.

In the phenoxy and benzoic acid series, substantial numbers of isomers, homologs and derivatives have been investigated, so that certain tentative generalizations concerning the role of the finer structure appear permissible. Of paramount importance for growth-regulatory activity is the substitution of certain of the ring hydrogens. Many of the unsubstituted parent compounds are virtually inactive. The kind, number and position of the substituent atoms or groups all are influential, but the precise role of each seems to vary with the particular parent series.

In the phenoxy series, activity is imparted by substitution in the 4-, 2,4- and 2,4,5- positions and, to much smaller degree, in the 2-, 3- and 2,5- positions. Halogen substituents are more effective than any other. Activity increases with number of substituent halogen atoms up to two or three but falls off with further halogenation. Other substituents, such as alkyl, nitro and hydroxyl groups, may increase activity, especially if halogen substituents are present in addition.

Halogen substitution increases activity in the phenylacetic and benzoic acids also, particularly if as many as three substituent atoms are present. In the benzoic series the nitro group has a very marked activating influence, especially in mixed-substituted compounds also containing halogen. Introduction of methyl, hydroxyl or amino groups into active halogen- or halogen-nitro substituted compounds often diminishes the activity. The most favorable positions for substitution in the benzoic acids are 2, 3 and 5, in contradistinction to the phenoxy acids in which they are 2, 4 and 5.

In general, the presence of a free carboxyl group is not essential. Activity comparable with that of the acids is exhibited by many of the corresponding salts, amides and esters. Indeed, in numerous instances such derivatives seem to have appreciably greater activity than the acids themselves, a circumstance which weakens but does not negate the view that *in vivo* hydrolysis to the acid is a prerequisite to physiological action. Nitriles, thioacids, alcohols and ethers also may possess activity.

The length of the carboxyl-bearing side chain may be of great importance. Substitution of the 2,4-dichlorophenoxy radicle on the omega carbon of the straight chain aliphatic acids confers activity only on those with an even number of carbon atoms (acetic, butyric, caproic, caprylic), whereas the odd-numbered (propionic, valeric, enanthic) are relatively inactive. This appears to hold also for naphthoxy-substituted compounds but not for indole-substituted. It has been suggested that

TABLE I
SUMMARY OF ACTIVITIES OF VARIOUS GROUPS OF GROWTH-REGULATORS

Class of Compounds	*Activity*						
	Stimulation of Cell Elongation	*Stimulation of Cell Division*	*Root Initiation*	*Modification of Organs (Formative effects)*	*Parthenocarpy*	*Retardation of Abscission*	*Bud Development*
Indole-aliphatic acids	+++	++	+++	±	+		inhibition
Phenyl-aliphatic acids	+	+	+	0	±		stimulation
Naphthyl-aliphatic acids	++		+++	±	++	+++	inhibition
Benzoic acids	±	++	++	++	++		
Phenoxy-aliphatic acids	+++	+++	+++	+++	+++	+++	inhibition
Naphthoxy-aliphatic acids	++		++	+++	+++	++	
Aromatic substituted carbamates	0	inhibition (mitotic aberrations)	0				
Carbon monoxide	++		++	0	0		
Unsaturated aliphatic hydrocarbons	+++		+++	0	0	-	stimulation

+++ high activity
++ moderate activity
+ slight activity
± very slight or doubtful activity
0 inactive
– acceleration of abscission

the higher-membered even carbon acids may be degraded *in vivo* by successive beta-oxidations to the active phenoxyacetic acid, which could not be formed in this way from the odd-numbered acids.

Where substitution of the aromatic residue is on the alpha carbon, the propionic and butyric acids frequently are more active than the lower or higher homologs, or than various dicarboxylic acids.

The indole compounds occupy a somewhat special position among growth-regulators inasmuch as the only naturally occurring plant hormone, the existence and identity of which is beyond question, is heteroauxin or indole-3-acetic acid. Indoleacetic acid appears to be widely distributed in plants, and it seems to be tacitly assumed, if not dogmatically claimed, that it is the central "growth-regulator" common to all chlorophyllous plants. An enzyme capable of oxidizing indoleacetic acid to an inactive product has been demonstrated in some plants. Such enzymic destruction might account for the lower apparent activity exhibited by indoleacetic acid in some responses in comparison with "foreign" compounds, with which the plant is less well able to cope. Halogenated or otherwise substituted indole acids have received only scant attention, although active compounds might logically be sought among them.

A quite different aspect of the relationship between structure and biological properties of the compound may also have to be taken into account. Employment of weed control methods involving soil applications rather than top treatments will call for compounds not readily decomposed or inactivated by the soil microflora and, therefore, capable of persisting in the soil and preventing development of weeds in the crop for a whole season. From this standpoint 2,4,5-trichlorophenoxyacetic acid would be preferable to 2,4-D, for example, in the pre-emergence weed control treatment of corn.

Mechanism of Action

Many of the responses which have been described for plant growth-regulators appear to depend ultimately upon alterations in the rate or direction of cell enlargement or of cell division. In addition, various biochemical processes involved in metabolism of carbohydrates and nitrogenous substances may be influenced, either with or without detectable morphological changes. While the causal relationship between the biochemical and structural responses is not clear at the moment, it may be presumed that the more complex morphological effects are initiated by chemical processes.

It is uncertain, too, whether or not diverse growth-regulatory compounds act fundamentally in a similar manner, that is, whether there is a common controlling mechanism which can lead to various end results. A satisfactory explanation must reconcile the following observations: (*a*) a variety of compounds may produce the same end result; (*b*) a single compound may bring about several apparently unconnected responses; (*c*) two compounds may behave entirely similarly with respect to one physiological effect but disparately in some other response; (*d*) even though the same general response, such as root initiation or cell elongation, may be brought about by different compounds, there may be found more or less marked qualitative differences in the character of the response; (*e*) plants classified in the same family or genus and which presumably have strong biochemical affinities may not respond in the same manner to particular growth-regulators.

One current view is that exogenous growth-regulators act by influencing, accelerating or blocking the biochemical processes controlled by indoleacetic acid or other cellular growth-regulators. However, understanding of the physiological role of the endogenous hormones is still so incomplete that it is not possible yet to formulate any common mechanism of action. There is some evidence indicating that the exogenous growth-regulators may be effective only at a particular stage in the development of cells and tissues and that the morphological and formative changes that result from treatments are limited to cells at this stage during the time when the chemical is applied.

Certain compounds, such as the phenylcarbamates, cause great cytological aberrations; other major groups, such as the phenoxy- and naphthoxy- compounds, bring about marked histological changes without apparent cytological disturbances.

Because of the diversity of chemical structure of active growth-regulators, some investigators have inclined to the view that their common characteristic might be some physical property and that their activity might be of a physicochemical nature, such as an influence on permeability.

Future Agricultural Uses

Up to the present the main agricultural outlet for growth-regulatory chemicals has been for weed control and weed eradication. The current pre-occupation with 2,4-dichlorophenoxyacetic acid for these purposes is hardly likely to be maintained. 2,4-D is a broadly effective and highly inhibitory compound; others that are safer to use or better suited for particular purposes are already known, and it may be confidently predicted that still others remain to be discovered.

Developments in weed control conceivably could result in far-reaching changes in cultural practices. Some rotations and many agricultural operations have been adopted primarily for purposes of weed control. A greater measure of chemical control of weed competition in the growing crop would surely allow more intensive cropping and, therefore, require greater attention to be given to the nutrient status of the soil. The per acre yield of corn can probably be appreciably increased if the old 42″ check row spacing is abandoned. Developments in the selective use of growth-regulators for weed control may well result, therefore, in greater demand for fertilizers in order to support more intensive land use.

Considered from the standpoint of the crop, the present herbicidal uses of growth-regulators are all indirect. The underlying principle is the prevention or removal of weed competition. The future holds great possibilities for direct uses involving application to the growing crop for purposes of crop growth-control. Most of the presently developed specialized horticultural uses, which involve rooting, flowering or fruiting, fall into this category. The common field crops that bulk large in producing the food and fiber of the world may be as susceptible to control as are those horticultural and fruit crops that have hitherto received more attention. Moreover, other uses, for which there are as yet no precedents, will likely follow.

The situation now confronting the agronomist and horticulturist is that some of the characteristics of plants previously accepted as fixed are in fact not immutable, and that agricultural and horticultural systems and practices developed on such assumptions may undergo great change. One of the goals of scientific agriculture in the past has been to secure for every locality plants fully adapted to that environment, and capable, therefore, of making maximum yields under the prevailing climatic and edaphic conditions. A long-season plant may not mature in northerly latitudes; a plant requiring high night temperatures may not be fruitful if the temperatures are low. It is highly probable that some of the factors governing plant adaptation will be susceptible to control or circumvention by growth-regulators. This may result in higher yields or a greater certainty of yield. Furthermore, it may result also in some change in crop distribution. Flowering time, flower abundance, fruit and seed setting, and maturity date may be susceptible of control. In a late season, flowering of some plants might be advanced in order to obtain maturity before the frosts of autumn. In an early spring, bud development and flower opening in fruit crops might be delayed to obviate late frost injury. Parthenocarpic fruit setting may be widely practiced with the result that seedless or almost seedless fruits and vegetables become common; the dependence upon insects and other natural pollinating agencies may be reduced and so provide greater latitude in the use of insecticides.

Visible changes in the morphology or yield of the fruit or grain, or other edible part of any crop, may be accompanied by changes in chemical composition. As yet this aspect has been little studied. The indications are that the balance between reserve carbohydrates and simple sugars may frequently be changed as the ripening process is delayed or accelerated by growth-regulators. There are reports that grain from wheat treated with 2,4-D for weed control may have a higher protein content, and that parthenocarpic tomatoes are sweeter than those produced by pollination. Information along these lines is very scanty; although not all such changes may be desirable, there is basis for the prediction that some measure of control of composition and, therefore, of quality is likely to be achieved.

The combination of crop control and composition control might be of outstanding importance with certain grasses and forage crops. The digestibility, palatability and feeding value of pastures decline rapidly as the dominant grasses head and mature. Delayed heading, or inhibited heading, with a resultant permanently vegetative leafy plant, might greatly change the quality of pastures and permit more intensive use of grazing land and meadows in the humid regions.

Research in the general fields of weed control and crop control is at present proceeding largely in an empirical manner. Interest is centered on 2,4-D and naphthaleneacetic acid or their derivatives. One of the main factors at present retarding the development of new growth-regulators and additional uses for such substances is the lack of fundamental knowledge as to the mechanism of action of this class of compounds. The horizons of the future are not yet clearly discernible. The potentialities and limitations cannot, therefore, be sharply outlined, but it is certain that agricultural practice may be greatly changed in form and direction by the availability of these new chemical tools.

Forest-Tree Genetics Research: *Populus* L.

The genus Populus, because of its considerable economic importance coupled with favorable experimental characteristics, has attracted the interest of many investigators of tree genetics and may truly be called the "guinea pig" of forest-tree breeding.

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Introduction

With the possible exception of the pines, no forest tree genus of the northern hemisphere has received so much attention from forest geneticists and tree breeders as has *Populus*. The results of these studies have been published in numerous widely scattered journals and bulletins, some of which have very limited circulation and availability. This review represents an effort to assemble the available data, but no claim for completeness is made.

At least two valuable reviews have appeared in recent years which discuss forest genetics research in *Populus*, but both have limitations. Richens (204) reviewed the entire field of forest tree breeding and genetics research since 1930, and Farrar's review (83) is limited to an account of the work in Canada.

The poplars are, in general, characterized by rapid growth rates, ease of propagation by twig or root cuttings, and winter hardiness. All are wind-pollinated, essentially dioecious[1], hybridize readily within and between most sections of the genus, and are capable of successfully maturing immediately viable seed on cut twigs in the greenhouse. In the Baltic regions and in central Europe intensive mangement of various species and hybrid clones has been practiced for many years. In North American forestry most poplar species have only recently evolved from the "weed" category, and in consequence an increasing interest in this group is being demonstrated by Canadian and American foresters. With these generally attractive biological characters and sympathetic economic circumstances prevailing, it is not remarkable that considerable interest has been directed to this genus by forest geneticists and tree breeders in this part of the world and abroad.

Classification and Nomenclature

Populus is represented by about 30 tree species which, except for one species[2], are confined to the temperate regions of the northern hemisphere. The genus is divided into five sections: (*a*) *Leuce* Duby (white poplars, aspens); (*b*) *Leucoides* Spach; (*c*) *Tacamahaca* Spach (balsam poplars); (*d*) *Aegeiros* Duby (cottonwoods, black poplars); and (*e*) *Turanga* Bunge (201). The geographical ranges of these natural divisions, as indicated by their principal species, are shown in Table 1 wherein the classification, nomenclature and ranges follow essentially those of Rehder (201).

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[1] Hastings (102), Erlanson and Herman (82), Aljbensky (3), Peto (193) and, doubtless, others have reported some members of the genus as showing a monoecious or polygamo-monoecious habit. East (80) believed the occasional perfect flowers to be self-fertile.

[2] *P. Denhardtiorum* (Engler) Dode, native of equatorial east Africa (78).

It will be noted that only one section (*Leuce*) is represented in the three principle regions where poplars are found and that Europe has only three native species in two sections (*Leuce* and *Aegeiros*). These three species, however, with some of their numerous named varieties and hybrids are all of considerable importance in European forestry practice.

TABLE I

Populus: GEOGRAPHICAL RANGE BY PRINCIPAL SPECIES

Section	*North America*	*Europe and Western Asia*	*Central or Eastern Asia*
Leuce	*P. grandidentata* Michx. *P. tremuloides* Michx. *P. Brandegeei* Schneid.[3]	*P. alba* L. *P. tremula* L.	*P. alba* L. *P. tremula* L. *P. Sieboldii* Miq. *P. adenopoda* Maxim.
Leucoides	*P. heterophylla* L.		*P. lasiocarpa* Oliv. *P. Wilsonii* Schneid.
Tacamahaca	*P. angustifolia* James *P. acuminata* Rydb. *P. trichocarpa* Hook. *P. tacamahaca* Mill. (= *P. balsamifera* L.?)[4]		*P. Simonii* Carr. *P. yunnanensis* Dode *P. szechuanica* Schneid. *P. tristis* Fisch. *P. cathayana* Rehd. *P. Maximowiczii* Henry *P. koreana* Rehd. *P. laurifolia* Ledeb.
Aegeiros	*P. deltoides* Marsh. *P. Sargentii* Dode *P. Wislizeni* (S. Wats.) Sarg. *P. angulata* Ait.	*P. nigra* L.	
Turanga		*P. euphratica* Oliv. (No. Africa to central Asia) *P. Denhardtiorum* (Engler) Dode (Tropical east Africa)	

The 12 species indigenous to North America represent four sections, but only four or five of the species (*tremuloides, grandidentata, tacamahaca, trichocarpa* and *deltoides*) occur at present in sufficient quantity to be of commercial importance.

Considerable taxonomic difficulty prevails in the genus with regard to the proper nomenclature to be used for certain species, varieties, forms or hybrids of the several polymorphic and easily hybridized species. A number of workers have striven to bring some measure of order out of the chaos. In Great Britain Elwes and Henry (81), Henry (109, 111, 114) and Cansdale (55) have contributed to taxonomic clarification of the especially difficult and confused section *Aegeiros*. Houtzagers (116, 119) in Holland; Dode (77), Régnier (198, 199), Guinier (99), Meunier *et al* (172) in France; Gombocz (92) in Hungary; and Sargent (210, 211) and Rehder (201) in the United States have also provided revisions and revaluations in nomenclature for various sections of the genus. Stout (236) and Stout and Schreiner (239) have emphasized the taxonomic confusion introduced by the early practice of assigning Latin binomials to natural or artificial F_1 hybrids which have been propagated vegetatively as clones. A further element of confusion is provided when, as in the case of the artificial hybrid X *P. generosa* Henry, it is found that not one but several sibs of both sexes, all vegetatively propagated, masquerade under the same name. The genetic ambiguity surrounding the binomial X *P. generosa* is, however, a comparatively ephemeral mist, not to be confused with the special degree of genetic confusion associated with such natural native hybrid names as X *P. Jackii* Sarg. (= *tacamahaca* × *deltoides*) and X *P. Andrewsii* Sarg. (= *Sargentii* × *acuminata*), each one of which is used to designate an entire hybrid swarm occurring in regions of range overlap of the parent species. Such mass grouping appears to be a legal and probably justifiable expedient on taxonomic grounds, but from the standpoint of genetic studies it is obviously unsatisfactory.

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[3] = *P. monticola* Brandegee. This imperfectly known species (47), endemic of southern Lower California and Sonora, is believed by Sargent (209, 210) and others to represent the New World counterpart of *P. alba* which it closely resembles.

[4] *P. balsamifera* L. is considered to be a *nomen ambiguum* by some authors; not so by others (116, 207).

Forest genetic literature relating to the poplars is, as a result, especially rich in taxonomic confusion. Workers with such genetically obscure material have an understandable reluctance to assign authority names to the scientific names used, and it is therefore often difficult even to identify the section to which a plant name in question actually belongs. But even such apparently satisfactory names as "*P. canadensis* Moench", complete with authority, may be quite meaningless. Due to the ambiguity contained in the original description made by Moench, the name has been attributed to at least five species and three hybrids in two sections by various taxonomists (55).

The determined attitude of poplar specialists in Europe to establish a practical working basis for taxonomic problems is reflected in the activities of the Commission International du Peuplier (21). Through a careful tabulation of the numerous clonal lines of poplars, especially of the section *Aegeiros*, cultivated in Europe, and with due regard to the International Rules of Botanical Nomenclature, this body proposes to secure a functional standardization in nomenclature to replace the present prevailing inextricable confusion.

A step in the right direction in this country was the precedent established by Schreiner and Stout (227) when they assigned clonal names, such as "Frye" and "Rumford", to ten of their selected hybrid clones. It is becoming increasingly apparent that individual names or numbers for such vegetatively propagated individuals, regardless of their taxonomic status as "species", "varieties", "forms", "hybrids", *etc.*, must be adopted by forest geneticists and breeders if any semblance of order is to be established in the genetic nomenclature.

Utilization

The wood of the American and European species and varieties of poplar is employed in considerable quantities for pulp, match-sticks and boxes, excelsior, veneer, small dimension lumber for interior trim, boxes, crates, wooden shoes and numerous other small articles of woodenware (52, 196, 120). Of peculiar interest is the fact that the natives of Kenya Colony, Africa, use the native *P. Denhardtiorum* in the manufacture of their dugout canoes (34).

Although long used and of respected industrial position in Europe and South America (Chile and Argentina) (196), poplar wood in this country has slowly gained in popularity for more general use only during the past decade. This increasing popularity, however, has probably been due to the demands of necessity resulting from the gradual elimination from the trade of various preferred species rather than to any fundamental change in relative value concepts.

The awakening interest in the use of poplar wood in the United States is best demonstrated by the stimulated activity in utilization research designed to find new uses and improve old processing techniques for trembling and largetooth aspen (*P. tremuloides* and *P. grandidentata*) in the Lake States. Due to poor cutting methods and lack of fire control, the original pine lands in this area were converted to almost pure stands of aspen early in this century (88). In the combined forested areas of Michigan, Wisconsin and Minnesota, aspen today is said to be of primary importance on some 20 million acres, representing 40 percent of the commercial forest land area (70).

In 1947, through the active interest of the United States Forest Service's Lake States Forest Experiment Station, a series of 21 reports on the aspen situation in that area were undertaken by members of this organization and other cooperating agencies. Most of these reports are now available (56, 62, 65, 89, 137, 146, 197, 205, 208, 213, 215, 232, 241, 250, 258, 293, 294, 297). Twenty of the bulletins are concerned with the technicalities of utilization and exploitation of this newly discovered wealth, but at least one (297) is devoted to summarizing the limited silvicultural data on aspen which have accumulated in this country.

Selection from Wild Stock

It is generally accepted by plant breeders that an initial step in a breeding program should involve a careful evaluation and selection of breeding stock from the wild type. Although conceded and recommended by tree breeders in this country (221, 231, *etc.*), there is no published evidence to indicate that such studies have been undertaken with the native poplars.[5]

In the United States the various wild species, forms and hybrids of *Populus*, both native and exotic, were claimed by Stout and Schreiner (239) to be incapable of fully satisfying the demands for direct use in reforestation projects. In spite of this observation a search for superior wild individuals to be used either directly as clones or as parental stocks for progeny tests and hybridization studies appears logical and justified. In view of the wide range of climates occupied by many of the North American poplars, it might be anticipated on the basis of Turesson's (261, 262) conclusions and those of Clausen, Keck and Hiesey (57, 58, 59) that a probable wide range of genetic variability exists in the wild populations of our native species.

Contrary to the complacency exhibited in this regard in this country, considerable effort has been directed in Europe to the selection of natural hybrids, varieties and élite forms of poplars for direct use in forest plantations or as parental stock in simultaneously conducted progeny tests and breeding programs.

In France, Belgium and Holland, where the black poplars are grown under intensive management for veneer, match stock and small dimension lumber, the majority of cultivated clones have been selected from natural variants of the native black poplar (*P. nigra* L.), introduced forms of *P. deltoides* Marsh., *P. angulata* Ait. and chance hybrids which have occurred between them since introduction of the American forms in the latter part of the 18th century.

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[5] Tests of wild élite forms of native poplars are, however, currently under investigation at the Mayo Forestry and Horticultural Institute, Rochester, Minnesota, in collaboration with the Forestry Department of the University of Minnesota; at the Department of Pathology, University of Wisconsin, Madison, Wisconsin; and at the Cabot Foundation for Botanical Research, Harvard University, Harvard Forest, Petersham, Massachusetts.

These "Hybrides Euraméricains" include the so-called "Régénéré de 'Ourcq", a clone of the cross *deltoides* × *nigra* and variously referred to in the literature as X *P. regenerata* Henry or X *P. canadensis regenerata* ((Schneid.) Rehd. var.). This clone, although susceptible to canker, is much prized for its rapid growth rate and good wood quality and is said to be the most important in France in number of trees and surface occupied. Other important clones are the "Vieux noir"; "Suisse", or "Black Italian Poplar" (X *P. serotina* Hartig = X *P. canadensis serotina* (Hartig) Rehd.); and still others of the same hybrid origin called "Blanc de Poitou" and "Raverdeau blanc". The clone of an *angulata* × *nigra plantierensis* cross (X *P. robusta* Schneid.) is of importance in the production of match stock. This is a rare case of specificity in the naming of clones, for it is believed that only one seedling of the cross was propagated (55).

In addition to the above, clones of the following are currently planted to a considerable extent in Holland: X *P. gelrica* Houts. (= X *P. serotina* × X *P. marilandica*); X *P. serotina* Hartig var. *erecta* Henry; X *P. marilandica* Bosc.; X *P. berolinensis* Dippel (= *P. laurifolia* × *P. nigra* var. *italica*); and X *P. regenerata* Henry var. *erecta* Houtz. (116, 119, 120). For further data on the clonal lines propagated in western Europe, the following references may be consulted: 1, 21, 31, 32, 107, 152, 172, 198, 237.

Interest in the use of poplars for forestry purposes has been manifest in England in recent years. Henry (112), Lotbinière (166, 167) and Ackers (1) believe the growing of poplars under forest management to be economically sound, provided desirable stock and suitable sites are utilized. This has encouraged search for the most desirable wild forms best suited to the plan of management and utilization. A valuable initial step in this direction was accomplished by Cansdale (55) in his "The species and hybrids of *Populus* cultivated in Britain". An accumulation of other supplementary evaluating information on individual members of the genus has also been made by the same author.

Cansdale and Ackers believe that X *P. regenerata* Henry and another clone of the same hybrid origin (*P. regenerata* Henry var. *erecta* Houtz.) may well prove to be valuable timber producers in the British Isles as they have in France. These clones have been grown successfully in forest plantations in England for a full rotation (40–60 years) in several localities with high yield.

According to Ackers, other native clones or introductions, including most of the black poplar varieties or hybrids grown on the continent, are promising for forestry use. The species *P. yunnanensis* Dode, a balsam poplar of China, and *P. trichocarpa* Hooker of the Pacific coast region of North America are being tested in forest plantations on various sites in the British Isles.

Interest in wild selection of poplars in Germany is chiefly reported in the work of Wettstein (271, 278, 279, 280, 282, 283, 285). This investigator (276) indicated that studies of climatic races in various species of *Populus* and other genera have been carried on by the German Association for the Breeding of Forest Trees.[6] Isolation of at least two climatic strains of *P. tremula* L. was later reported by Wettstein (278), and reports of progeny studies, showing variation among the seedlings of *P. tremuloides* Michaux and *P. tremula*, were made by the same author (280).

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[6] Established through the interest of Erwin Baur in 1932.

Vill (264) reported that the hybrid X *P. charkowiensis* Schröder [possibly X *P. canadensis Eugenei* (Simon-Louis) Schelle, the "Carolina Poplar", commonly planted as a street tree] is being grown extensively in the Rhineland. Although the clone under plantation conditions is said to make very good growth and to show considerable promise as a timber producer, it is, nevertheless, subject to canker.

In Sweden the Swedish Forest Tree Breeding Institute (Ekebo, Källstorp, Sweden) has directed considerable of its effort to the isolation of superior wild forms of *P. tremula* as a normal initial step in its aspen-breeding program (144). Selected trees must conform to high standards of stem form, branching habit, health and vigor before being acceptable for progeny tests and breeding studies. The discovery of nine clones of natural triploid *P. tremula* (42, 180, 138, 257), resulting from such surveys of wild stands, gives promise of supplying valuable wild material for direct forestry use and further breeding. According to Nilsson-Ehle (180, 182), the first triploid clone which was discovered in south Sweden grows more rapidly, produces more wood per year and is believed to be more resistant to attack by *Polyporus* sp. than the normal diploid form. Also, because of its "stronger growth", it is reported as able to succeed in competition with lime, maple, elm and other hardwoods. The native diploid, on the other hand, is said to be found only on the outer margin of such mixed hardwood stands in southern Sweden. Tests of the triploid, or "gigas" form, have revealed its value for use in the match and paper pulp industries. The form is reputedly easy to reproduce by root cuttings, and, since diploid x triploid crosses have been successful in producing a number of tetraploid forms (246), it has now been possible to produce triploid seed at will by diploid x tetraploid crosses (142, 143).

Jablokov (125) in Russia has also reported discovery of a giant form of *P. tremula* which appears to be endowed with the same generally favorable characters as the Swedish form. Under the currently unfavorable position enjoyed by classical genetics in that country (212), the discoverer of the Russian form was inclined to attribute its origin to "vegetative propagation", though polyploidy was not excluded as an alternative.

Controlled Hybridization and Selection

Since 1912, when Henry (110, 111) synthesized X *P. generosa* Henry by the intersectional cross *P. trichocarpa* Hooker x *P. angulata* Ait., a large number of crosses within the genus *Populus* have been effected by various workers.

Johnson (130) compiled a list of 121 natural and artificial crosses in the genus in 1939. This list was later revised by Smith and Nichols (231) who omitted crosses involving parents of doubtful identity, thus reducing the number to 93. Smith (230) provided another revision, resulting in a total of 83 crosses. A tabulation of the parents of these crosses by section were made by the same author; the resulting data are recorded in Table II.

For further summaries or original reports of inter- and intraspecific, double, or back-crosses in the genus, the following may be consulted: Schneider (217), Wettstein (273, 274, 275, 278, 284), Aljbensky (4, 5), Stout and Schreiner (239), Cansdale (55), Heimburger (103, 104), Johnson (130), Johnson and

Heimburger (136), Svoboda (243) and Richens (204).

Most workers have placed particular emphasis on interspecific crosses within the sections *Leuce*, *Tacamahaca* and *Aegeiros*, and between the latter two sections. In these combinations there is apparently unlimited compatibiilty. A few intersectional crosses involving species of *Leuce* x *Tacamahaca* and *Aegeiros* have been made. One intersectional cross (*P. lasiocarpa* x *P. nigra*) involving the sections *Leucoides* and *Aegeiros* is recorded (204), but no other record of crosses involving *Leucoides* and none for *Turanga* has come to the author's attention. On the basis of the degree of compatibility demonstrated in the other sections of the genus, it would seem unlikely to be absent in these.

TABLE II

NATURAL AND ARTIFICIAL POPLAR HYBRIDS WITHIN AND BETWEEN SECTIONS

Leuce X *Leuce*	*Leuce* X *Tacamahaca*	*Leuce* X *Aegeiros*	*Tacamahaca* X *Tacamahaca*	*Tacamahaca* X *Aegeiros*	*Aegeiros* X *Aegeiros*
14	2	4	7	28	28

Hybridizing Technique. Early hybridization studies in *Populus* were carried out through the laborious method of bagging mother trees *in situ* (238, 239), but with rediscovery of the "greenhouse methods", poplar hybridization has become amenable to modern mass production methods. Yanchevsky's (292) cut twig method, first used for hybridizing *Salix* species, in which flower bud-bearing branches of the intended parents are cut and conveniently placed in jars of water on the greenhouse bench and forced at will, was rediscovered by Wettstein (271) and successfully applied by this worker and others (140, 231, 133, *etc.*) to the poplars. A further elaboration of this technique was supplied by rediscovery of the ancient "bottle-grafting" method (41, 128, 129, 160, 290) which not only assures a greater degree of success with species that quickly mature their fruits (*Populus* and *Salix*) but makes greenhouse hybridization possible with other genera as well. By this method, branches bearing female flower buds are placed in jars of water on the greenhouse bench and are then united, in the manner of an approach graft, with the stem of a seedling of the same species growing in a pot. When the union is effected the lower portion of the branch (scion) is removed from the bottle of water and pruned off close to the point of union. It is claimed that such "dwarf trees" may continue to produce flowers and mature fruits periodically for several years.

A somewhat similar technique is suggested by current studies of bud and rootstock compatibility being conducted by the present author (187). Willow flower buds budded on a poplar hybrid rootstock in August, 1946, opened and developed with apparent normality in the spring of 1947. It is thus suggested that flower buds of desired parents might be budded on the same or different potted rootstocks and hybridized in the greenhouse. In this connection it would be of interest to determine whether the isolating mechanism of different flowering times effective between two species of overlapping range in nature might be altered by budding both on the rootstock of another species.

By use of the greenhouse hybridization methods the early practice of selecting mother trees on the basis of their ease of access in arboreta or on boulevards rather than on the basis of more pertinent genetic characters has been essentially overcome. Twig material bearing flower buds may now be collected in the dormant condition from élite trees any place in the world where air transport is available and shipped to any other point for crossing under greenhouse conditions. The crossing of an individually superior European aspen, for instance, selected in Sweden, with an individually superior Chinese aspen from central China may now be accomplished with a minimum of effort and expense in a greenhouse in the United States.

United States. With the exception of the early tree hybridization experiments of Klotzsch, Ness and Henry, and the chestnut breeding work of Van Fleet and Graves, the first formally designated tree-breeding project was that started in the genus *Populus* in 1924 by the Oxford Paper Company, Rumford, Maine, in collaboration with the New York Botanical Garden. This work was conducted and reported by Stout, McKee and Schreiner (238), Stout and Schreiner (239, 240) and Schreiner and Stout (227).

The preliminary objective of the program was to evaluate and test the known species and hybrids of *Populus* on the basis of their value for pulpwood reforestation and to produce through hybridization more valuable types than those in existence. As previously pointed out, however, there are no available data to indicate that the evaluating and testing of the known species and hybrids were actually carried out. There is, on the contrary, abundant evidence that the hybridization program was prosecuted with vigor. About 13,000 hybrid seedlings were obtained from about 100 successful cross combinations. Thirty-four different poplars were involved as parents: three white poplars and five aspens (Sec. *Leuce*); 17 black poplars or cottonwoods (Sec. *Aegeiros*); and nine balsam poplars (Sec. *Tacamahaca*). The sections *Leucoides* and *Turanga* were not involved. A detailed list of individual crosses has not been incorporated in this review but they are available in the original papers by the authors noted above and in the list of hybrids compiled by Johnson (130).

Initial selection of the hybrid population, based primarily on vigor of growth, was made during the second year. Six hundred seedlings were thus selected. The remainder, and also those weeded out by subsequent selections, were planted in a forestation plantation. Cuttings of the selected plants were also thus planted. Significantly, some of the earlier discarded plants were later selected on the basis of their performance in the forestation planting.

The second selection reduced the number of selected clones to 69. All of these were hybrids within or between the sections *Aegeiros* and *Tacamahaca*. In most cases two or more sister hybrids were represented among the 69 selected individuals. From the cross *P. nigra* × *P. laurifolia* a total of 377 hybrid seedlings were grown, and of this number ten were among the 69 selected plants.

Schreiner and Stout (195) described their finally selected hybrids on the basis of vigor of growth, ability to root from stem cuttings, hardiness and resistance to disease. Since the descriptions were based on nursery stock and young trees, it was impossible to record the sex, form of tree, and character of the trunk. Ten of the clones were assigned horticultural names, as indicated in Table III. •

A number of the selected clones from these crosses have been given wide distribution for testing under various soil and climatic conditions in this country and in Europe, but no very extensive results of these trials have as yet been published.

A point of peculiar interest to tree breeders and forest geneticists is the fact that for some obscure reason certain of the hybrids produced in this hybridization study were patented in this country and also, reportedly, in Sweden by R. H. McKee, one of the authors of the first preliminary report (238).

TABLE III

LIST OF SELECTED HYBRIDS SHOWING CLONAL NAME AND NOMENCLATURE OF PARENTS, ACCORDING TO SCHREINER AND STOUT (227). AVERAGE DIAMETER AND HEIGHT AFTER SEVEN SEASONS OF GROWTH FROM STEM CUTTINGS AT MONT ALTO ARBORETUM, PENNSYLVANIA, ON WELL-DRAINED SANDY LOAM (13).[7]

Clonal Name	*Parentage*	*Average DBH (inches)*	*Average Ht. (feet)*
Frye	*P. nigra* × *P. laurifolia**	6.7	37.0
Rumford	*P. nigra* × *P. laurifolia**	3.2	27.0
Strathglass	*P. nigra* × *P. laurifolia**	3.0	24.0
Roxbury	*P. nigra* × *P. trichocarpa**	2.9	26.5
Andover	*P. nigra betulifolia* × *P. trichocarpa**	1.7	17.0
Geneva	*P. Maximowiczii** × X*P. berolinensis**	3.6	29.0
Oxford	*P. Maximowiczii** × X*P. berolinensis**	2.9	27.0
Rochester	*P. Maximowiczii** × *P. nigra plantierensis*	4.3	31.5
Androscoggin	*P. Maximowiczii** × *P. trichocarpa**	3.1	25.0
Maine	*P. candicans** × X*P. berolinensis**	2.1	17.5

* = of the Sec. *Tacamahaca;* all others of the Sec. *Aegeiros.*

Schreiner (220) reported that fiber length and density of wood of the finally selected hybrids had been preliminarily investigated. On the basis of average fiber length of one-year-old wood of the hybrids (0.8 – 0.85 mm.) as compared with fiber length in one-year-old wood of *P. tremuloides* (0.53 – 0.57 mm.), the hybrids appear to be definitely superior. It was also noted that wood of the hybrids was somewhat denser than wild aspen wood grown in western Maine. This is believed to have been due primarily to the proportionately larger vessel volume, *i.e.*, greater per cent of air space per unit volume, in wood of the slower growing aspen. Schreiner's conclusions on density concur with the observations reported by Paul (185) in the case of other diffuse porous hardwoods grown under extremely adverse conditions. The resultant narrow rings contain abnormally large percentages of porous tissue with corresponding decrease in specific gravity and hardness of wood.

Johnson's (132) results from studies of the relation of growth rate to wood quality in hybrids involving *P. alba, P. grandidentata* and *P. tremuloides* are of interest in this connection. This investigator found that, although fiber length in individual fast and slow growth annual rings from the same tree showed a marked tendency for fast growth rings to produce longer fibers, data from individual fast grown and slow grown trees did not show significant relation between fiber length and growth rate. In general he concluded that nothing was found that would support a contention that abnormally rapid growth is seriously detrimental to wood quality, and that breeding work designed to produce rapidly growing forest trees can proceed with some assurance that rapid growth and good wood quality are not incompatible.

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[7] See also Gruschow (97) and Silen (228).

Bray and Paul (48) compared the pulping quality of trembling aspen with various hybrid poplars and observed that the growth rate of the hybrids was greater and the pulp strength higher. The pulp yields per unit weight of wood of the hybrids were, however, lower and their bleaching requirements greater. Interpretation of data in this study was confounded by a variability in quality which was noted along the stem of individual trees.

The hybridization and selection work with the poplars carried on at Harvard University through support of the Maria Moors Cabot Foundation for Botanical Research is as yet incompletely reported in the literature. A number of early interspecific crosses involving species of the sections *Leuce, Tacamahaca* and *Aegeiros* were reported by Smith and Nichols (231). These workers observed that crosses involving *P. maximowiczii* appeared to be most promising.

Subsequently, double-crosses of a clone of X *P. generosa* Henry with clones of X *P. Jackii* Sarg., X *P. berolinensis* Dipp. and X *P. robusta* Schneid. have provided progenies which are now established in permanent test plantations. Interest in this material is directed especially to an analysis of the correlation existing between the juvenile and adult expression of such characters as heterosis, stem form, branching habit and disease resistance as a means of determining the accuracy with which early selections may be made in hybrid poplar progenies. A report (186) by the author based on data accumulated during the first three years of observation of the *generosa* × *Jackii* progeny indicates that selection for heterosis during the first or second year of age is not entirely effective.

Other current poplar investigations under sponsorship of the Cabot Foundation are chiefly concerned with the study of ecotypic variability within the North American species of the genus. On the basis of preliminary observations it may be stated that intraspecific crosses involving élite parents of widely separated geographic origin hold considerable promise as sources of vigorous and otherwise desirable forms.

Germany. Hybridization studies in the genus *Populus* have been reported periodically by Wettstein (271, 273, 274, *etc.*) in Germany. Of a large number of intra- and intersectional crosses made, progeny of the following were reported as showing exceptional heterosis when compared to parental vigor:

P. alba × *P. tremula*
P. alba × *P. canadensis*
P. eucalyptus × *P. canadensis*
P. alba × *P. nigra pyramidalis*
P. tremuloides × *P. tremula*

Intraspecific crosses involving climatic strains of *P. tremula* were reported by Wettstein (278, 279, 285), and in most instances hybrid vigor of the progenies, based on the first season's height growth, was well marked.

The breeding work of Wettstein has not been directed primarily to the synthesis of rapidly growing forms but to the development of new forms less exacting in their site requirements. Poplar culture in Europe has so developed that the species *P. alba* and *P. tremula* have been almost entirely eliminated because of their slow growth, crooked stem form and normally small dimensions on poor soils in western Europe. In utilizing these species as parents, Wettstein has hoped to obtain hybrids showing heterosis and improved form but still making low site demands.

Wettstein's studies of ecotypic variability (250) demonstrated that ecotypes of *P. tremula* found in continental or cold regions have greater frost resistance and a shorter growing season with earlier entrance into dormancy than types of milder climates. Swedish and East Prussian *tremula* trees, for instance, when grown near Berlin, begin their dormancy in September, whereas *tremula* of western or southern provenance is still green in October.

In intraspecific crosses of *tremula,* involving various ecotypes, length of growing season of individual hybrids demonstrated noticeable variation from that of their parents. It is thus possible to synthesize forms best suited to a particular locality.

Canada. Heimburger (103, 104) in Canada has carried on rather extensive breeding studies in the genus *Populus.* This work has been reviewed recently by Farrar (83), and a summary of crosses undertaken is tabulated by Johnson and Heimburger (136). The object of the breeding program was to produce hardy and disease-resistant material of vigorous growth for the production of wood of high quality to meet the demands of the match, veneer and pulp industries of Canada. In addition some attention was directed to the development of material suitable for shelterbelt plantings in the prairie provinces.

In 1936 Heimburger reported the successful crossing of *P. alba* L. and *P. canescens* Sm. (considered by Heimburger, Wettstein and others to be of hybrid origin: *alba* x *tremula*) with *P. tremuloides* Michx. and *P. grandidentata* Michx. The cross *tremuloides* x *grandidentata* was also consummated.

Progeny of *alba* x *grandidentata*[8] and *tremuloides* x *grandidentata*[8] uniformly displayed characters intermediate between the two parents involved. Progeny of *canescens* x *grandidentata*, however, showed great variation in vegetative characters, thus providing further evidence of the presumed hybrid origin of *P. canescens.*

Heimburger later (104) reported tests of sprouting ability of root cuttings and hardiness of the above hybrids. At the end of the first growing season root cuttings were made of the hybrids and planted immediately in the nursery where they were allowed to over-winter. All of the *tremuloides* x *grandidentata* and *alba* x *grandidentata* clones survived, but a number of the *canescens* x *grandidentata* perished; whether this failure was due to lack of hardiness or poor suckering ability is not clear. In any case such physiological variation was anticipated on the basis of the high degree of morphological variation previously noted for this progeny.

Growth vigor and resistance to die-back caused by *Napicladium* sp. was selected for during the 1938–39 seasons. This resulted in removal of all the *tremuloides* x *grandidentata* hybrids. These plants showed medium to poor growth and great susceptibility to die-back, but, on the other hand, showed a fair degree of resistance to *Melampsora* rust. Heimburger suggested that such extreme susceptibility of some hybrids to disease may be added to the mechanisms of isolation which maintain species differentiation, as described by Dobzhansky (76).

Subsequent development of the *alba* x *grandidentata* progeny gave promise of valuable varieties available directly for reforestation plantings. Well-marked hybrid vigor, easy propagation by root cuttings, at least of juvenile material, and well-defined resistance to *Melampsora* rust and *Napicladium* die-back were shown.

A number of other successful crosses

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[8] Victorin (263) reported natural hybrids of these crosses in Quebec. Under normal conditions in Canada, however, *P. tremuloides* flowers about ten days before *P. grandidentata* but at about the same time as *P. alba* (88). Natural hybrids of the latter have been compared with the artificial and found to be identical (104). Tubeuf (260) reported natural hybrids between *P. alba* and *P. tremula.*

were later reported by Heimburger (104). Of genetic interest is the preliminary analysis of the mode of inheritance of branching habit indicated by the double cross: X *P. berolinensis* Dipp. × X "Northwest Poplar" (believed to be derived from natural crosses of *P. deltoides* Marsh. × *P. tacamahaca Michauxii* (Dode) Farwell var.). Since both parents in the cross are themselves hybrids of *Tacamahaca* × *Aegeiros* crosses, their progeny showed wide variation in vigor and leaf and stem characters. Of the 26 plants selected after discarding some dwarf seedlings, 12 showed the "excessive juvenile branchiness" character typical of X *P. berolinensis,* while the remaining 14 had the "clean stem" character. It was tentatively concluded that "excessive juvenile branchiness" is dominant to "clear stem" and may be transmitted to about one-half of the progeny in this cross. Branchiness is an undesirable character for the production of clear wood for various industrial purposes, but for shelterbelt material it is exceedingly desirable. For this reason the above cross was repeated on a larger scale, using other "Northwest poplar" material more resistant to *Septoria* canker and *Melampsora* rust.

Sweden. Hybridization studies in Sweden have been concerned chiefly with intraspecific crosses involving diploid and triploid forms of the native *P. tremula* and the especially promising *tremula* × *tremuloides* crosses which have been recently given wider scope by the introduction of ecotypes of wide geographic origin throughout the ranges of both species.

Johnsson (144) has noted that in comparative growth tests, F_1's of *tremula* × *tremuloides* have markedly superior vigor as compared to the native *tremula* and that the hybrids are not attacked by *Fusicladium radiosum* and only to a small degree by *Melampsora* rust. With respect to quality, however, progeny of some crosses of *tremula* élite trees are superior to the interspecific hybrids produced.

Nilsson-Ehle (181, 182) and Bergstrom (35) reported genetical and cytological studies of successful diploid × triploid crosses of *P. tremula.* The crosses were made primarily to determine the possibility of obtaining a tetraploid, since Müntzing (176) reported some giant pollen grains (with possibly the $3n$ complement of 57 chromosomes) produced by the wild triploid discovered in Skänc, Sweden. Interest in securing a tetraploid was prompted by the presumed feasibility of producing triploid seed at will by diploid × tetraploid crosses.

Of the approximately 100 plants obtained from one of the crosses, the majority were aneuploid (mostly hypotriploid), several were exactly diploid, one exactly triploid and one exactly tetraploid. All of the progeny proved to be healthy vigorous plants. The triploid and near-triploids, however, were distinguishable from the others by their extremely rapid height growth. The tetraploids fell somewhat below the triploid in vigor but had the largest leaves of all the progeny. The intermediate aneuploids showed poor development and were highly divergent in appearance, many dying at an early age.

These observations concur with Johnsson's (138, 139, 142, 143) studies of the progeny of diploid × triploid and triploid × triploid crosses of *P. tremula* which led him to conclude that triploidy represents the optimal degree of polyploidy in this species. The absence of tetraploid species or forms of *Populus* in nature, as far as is known, is cited as evidence that tetraploidy represents the limit of vitality in this genus.

Russia. Available reports of hybridization studies involving the poplars which have been undertaken in Russia appear to be confined chiefly to the publications of Aljbensky (= Al'bensky or Aljbenskič) (2–6), Jablokov (123, 124, 126) and Bogdanov (46).

The practical objective of the work of Aljbensky has been directed to the production of fast-growing, drought-resistant hybrids for use in plantations and windbreaks in the steppes. Promising hybrids have been derived from a number of intra- and intersectional combinations involving European and Asiatic representatives, some of obscure identity, belonging to the sections *Leuce, Aegeiros* and *Tacamahaca* (4, 22). Selections from the following crosses, propagated by cuttings and tested for four to seven years at Kamyshin (ca. Lat. 50° N. Long. 45° E.), were rated best on the basis of their frost-, drought- and borer-resistance, ease of propagation by cuttings, and adaptability to a wide range of soils (5):

P. balsamifera × X *P. berolinensis*
P. moscoviensis × X *P. berolinensis*
P. pyramidalis × *P. simonii*
P. pyramidalis × *P. nigra*
P. alba × *P. bolleana*

The hybridization experiments reported by Jablokov indicate pre-occupation with the atavistic trend of genetic theory sponsored by the Lysenko school, and his work is thus concerned essentially with providing purported proof of the theory of the plasticity of the genotype under various environmental, especially nutritional, influences.

According to this worker (123), an analysis of progenies of crosses involving *P. alba* and *P. tremula* demonstrated that plants derived from one catkin on the mother tree of a particular cross were all uniform but differed significantly from plants derived from other catkins on the same tree. Significant differences were also claimed between progenies derived from crosses on trees in the open air and those derived from crosses of the same individuals using cut twigs in the greenhouse.

The influences of the Lysenko school are also noted in the description of the "vegetative hybrids" of Bogdanov (46), said to be derived from adventitious buds arising from callus tissue on stumps cut at the union of stock and scion or one-year old grafts. The interesting suggestion that such "hybrids" may be chimeras or very possibly tetraploids of either stock or scion tissue is not noted by the author.

Mode of Inheritance. Data on the mode of inheritance of various characters in *Populus* are for the most part conspicuously lacking in the literature. This is largely due to the comparatively long time required for the plants to reach sexual maturity and the difficulties associated with the preservation of a sufficiently large sample of the F_2 to proved a statistical basis for study.

The dominance of certain characters in particular crosses has, however, been noted by various authors. Thus the fastigiate branching habit of *P. nigra italica* tends to be transmitted as a dominant (204, 178, 279, 126). Heimburger (104) noted the dominance of certain branching characters, and Johnson (134) has reported in some detail on the inheritance of certain characters in F_1 and F_2 hybrids of a *P. alba* × *P. grandidentata* cross. Of interest in this regard are the data on height for the parents, F_1, and F_2 hybrids:

	Average Height at six years (Ft.)[9]
P. alba	14.0
P. grandidentata	11.7
F_1	17.6
F_2 (168 plants)	9.5

[9] Parental and F_1 clones propagated by cuttings; F_2 plants are seedlings.

This appears to be the first comparative evidence of F_2 vigor reported in the genus.

Studies of photoperiodic response in *P. tremula* in Sweden (14, 244) and Germany (285) have revealed that day length is a critical factor in growth. Sweden with its wide range in the high latitudes (ca. 56° N. to 69° N.) is especially well suited to such studies. Of considerable interest to tree breeders are results of investigations which indicate that northern (long-day) races of *P. tremula* are dwarfed when grown at the lower latitudes (short days) of southern Sweden. But conversely, plants of southern origin are stimulated in growth when transplanted to regions of long-day in the north. In these cases, presumably, the limiting factor for survival of such plants is their frost resistance.

Studies of crosses between northern, southern and geographically intermediate forms revealed that plants of northern and southern origin were uniformly homozygous for long- and short-day response, respectively, whereas plants from central Sweden were heterozygous for these factors. It was further demonstrated that long day response of northern forms was inherited as a dominant character (14, 244).

Selection for Disease Resistance

A considerable literature on varietal resistance to the various poplar diseases has accumulated in this country and in Europe. No effort has been made here to summarize this literature in detail but the following references may be consulted.

In this country the problems of selection for resistance to cankers (*Cytospora* (= *Valsa*), *Dothichiza, Hypoxylon, Nectria, Septoria, etc.*), die-back (*Cytospora, Napicladium*) and leaf rust (*Melampsora*) have been discussed or investigated by Detmers (71), Hartley (101), Schmitz and Jackson (216), Schreiner (218, 219, 221), Stout and Schreiner (239), Schreiner and Stout (227), Heimburger (103, 104), Bier (36–38), Gruschow (97), Davis (66), Waterman (269) and others.

Investigations of varietal resistance in Europe are reported by Day (67), Day and Peace (68), Delevoy and Boudru (69), Wettstein (279, 283), Koning (148–151), Pelkwijk (191), Vloten (266), Peace (189, 190), Jablokov (126), Nilsson-Ehle (180, 181), Régnier (200) and others. The essentially taxonomic work of Regnier (198, 199) in France, Houtzagers (116) in Holland, and Cansdale (55) in England, to which reference has been made before, represented initial ground work for further pathological investigations.

Vegetative Propagation

The ability to produce root suckers or stump sprouts under field conditions appears to be characteristic of most species of poplar, and with some species, in certain areas, such asexual methods may provide the principle means of reproduction.

Baker's (26) study of aspen (*P. tremuloides aurea* (Tidestr.) Daniels) in the central Rocky Mountains emphasizes the almost exclusive dependence on root suckering as a means of stand reproduction and extension in that area. A somewhat similar situation apparently prevails in other regions of the United States and in Europe for the native aspens, but periodic reproduction by seed at favorable intervals, especially following fire, very likely occurs rather frequently.

In contrast to the aspens, the "cottonwood complex" (*P. deltoides*) of the eastern United States places little reliance on suckering in nature. Reproduction is chiefly by seed on the favorable seed beds present along the water courses where it occurs. The vigorous stump sprouting ability of young cottonwood is, however, exploited by the silviculturist (289).

The ability to root from stem cuttings under most conditions in high percentage without special treatment or handling appears to be characteristic of the species of *Tacamahaca* and *Aegeiros*. The members of the section *Leuce*, however, are in general considered to be "difficult" or "resistant" plants, and auxin treatment is usually required.

Snow (233) has demonstrated that dormant one-year old stump sprouts of individual trembling and largetooth aspen with which he worked could be rooted to the extent of 67 percent by treating with a 10 mg. per liter concentration of indolebutyric acid for 27 hours. Other treatments and results for individuals of other species of *Populus*, as well as other ligneous genera, have been summarized in a recent comprehensive review by Thimann and Behnke (251).

Although the aspens produce vigorous root suckers in nature, root cuttings as a rule prove an unreliable means of propagating older trees, even under nursery conditions. The cuttings usually produce abundant shoots, but high mortality at an early stage makes this method generally impractical.

A valuable technique for asexual multiplication of aspen and white poplars by stem cuttings which does not require auxin treatment has, however, been developed in Denmark (154, 155). Root cuttings are sprouted, and small soft-wood cuttings of the shoots are then made and rooted in sand. Such cuttings from aspen and gray poplar gave 80–100 percent rooting in 10–14 days.

Considerable inter- and intraspecific rooting variability has been noted by Canadian workers in the section *Leuce*. *P. alba* is in general said to be less resistant to rooting than the European or American aspens and shows noticeable interclonal variability in this character (83). Johnson (134) has indicated that the rooting capacity of *P. alba* is transmitted as a dominant character to its progeny in the cross *alba* × *grandidentata* but not in the cross *alba* × *tremuloides*. It was postulated that *tremuloides* carries an inhibitor for the *alba* rooting factor. Stout and Schreiner (239) observed that hybrids of the cross *deltoides* × *grandidentata* were characterized by the poor rooting character of the aspen. These workers, as well as Heimburger (104), have also reported clonal variation within the native cottonwood. Stout and Schreiner (239) stated that the rooting ability of some of their hybrids showed great improvement over rooting ability of either parents. The data upon which these conclusions were based or the specific cases involved were not, however, noted.

Thimann and Delisle (252) and Larsen (155) have discussed the vital influence of various circumstances, especially the age effect of the tree from which cuttings are taken, and several environmental factors (type of rooting medium, temperature, auxin concentration used, *etc.*), all of which exert a profound influence on the success or failure of root formation. On the basis of present evidence it is apparent that decisions with regard to the relative rootability of cuttings of various clones within or between species must be expressed in very general terms, unless careful duplication of treatment is used in the comparison.

It has been previously pointed out that one of the attractive features of this genus as experimental material for forest genetics and tree-breeding studies is closely associated with the ease with which most individually superior clones may be propagated by twig or root cuttings. From a practical point of view rootable twig cuttings are more desirable than sproutable root cuttings because of their ease of handling, planting, *etc.* under forest plantation conditions. This situation has produced a rather profound influence on the direction that poplar breeding studies have taken in this country and has possibly obscured certain paths of research which might be profitably investigated.

With the exception of the Canadian work (103–105), little or no interest in the improvement of aspens has been shown in North America. Although the aspens in this country were early discredited and essentially ignored (205), commercial interest in their utilization, as previously pointed out, has steadily increased. The fact that a general notion prevails as to their poor rooting ability should not invalidate them as valued material for tree-breeding studies. On the basis of the apparent clonal variability in *P. alba* with regard to this factor, there seems to be no logical reason to discount the possibility of its occurrence in trembling or largetooth aspen. This information, however, must be gathered by a systematic analysis of variability in the wild population and not through the testing of taxonomic specimens in arboreta.

Even in the complete absence of cutting rootability it does not seem logical to ignore possibilities of improvement for the native aspens. If tested inter- or intraspecific crosses which yield a progeny containing a sufficiently high percentage of superior individuals are found, it would seem advisable to enquire into the possibility of using a direct seeding method on especially adaptable sites.

Burned-over areas in New England and the Lake States might be profitably managed in this manner. With the stand established by direct seeding, possibly using pelletized seed, it might be cut for pulp on a short rotation and then managed as coppice for a second rotation. The generally beneficial results to the soil associated with accumulation of hardwood litter might then make the site more suitable for the establishment of other desired species more demanding in their site requirements.

Heimburger (105) has pointed out that the chief disadvantages of the cottonwoods and balsam poplars for forestry use lie in their requirements for a soil which is rich by forestry standards and their special demands for careful site preparation. Aspens, however, may be grown on almost any level of fertility.

These observations are supported to some extent by the fact that the natural habitat of cottonwoods and balsam poplars are strictly low river-bottomland or swamp borders, whereas aspens are notably ubiquitous. Although capable of occupying a wide range of sites, there is no doubt that the quality of the aspen stand produced is closely correlated with site quality (297).

Silvics and Culture

The silvical characters of the various poplars and cultural practices used in forest plantations and natural stands in several countries have been described by various authors. Forestry Commission Bulletin No. 5 (10) and Leaflet No. 27 (23) of the Forestry Commission provide a useful summary of cultivation methods in Great Britain. French practice is discussed by Breton-Bonnard (49, 50), Stout (237), Guinier (99) and d'Alviella (7). Interest in poplar cultivation in the Netherlands is discussed by Houtzagers (118, 120) and Meeiker (170); in Norway by Barth (33); and in Germany and Switzerland by Leiber (163), Zircher (300), Barbey (31), Wettstein (281, 283) and others; Bogdanov (43–45) discussed Russian methods. Weigel and Frothingham (270), Baker (24, 26), Williamson (289), Buttrick (54), Kittredge and Gevorkiantz (147), Bull and Muntz (53), Zehngraff (295–299), Stoeckler (235) and others have described silvicultural practices employed in the United States.

The important role of sod through its inhibiting influence on the successful establishment of poplar and other hardwood plantations has been studied and reviewed in considerable detail by Schreiner (224–226).

Chromosome Number

From lists of chromosome numbers and other reports published by various authors (40, 173, 86, 87, 253–256, 82, 39, 176, 177, 193, 169, 230, 64) it appears that the basic number in the genus *Populus* is 19.

On the basis of what he interpreted to be secondary association of chromosomes at metaphase I, Dillewijn (74, 75) concluded that *Populus* and possibly *Salix* are secondary polyploids with an original basic number of eight. Four of the original eight chromosomes, according to his hypothesis, have been triplicated, the other four duplicated, and the present number 19 was the result of a fusion of two chromosomes within one of the groups of three. Smith (230) gives further support to this hypothesis with the observation that trivalent association of chromosomes sometimes occurs in meiotic metaphase of certain diploid hybrids and quadrivalent formations in the triploid form of *P. alba.*

Of the approximately 45 species and forms of *Populus* which have been cytologically examined, the unreduced number of 38 chromosomes appears to be characteristic of most species, but naturally occurring triploid and experimentally produced tetraploid and aneuploid forms have been reported.

Blackburn and Harrison (40) reported *P. balsamifera* (= *P. deltoides* ?) as a probable tetraploid with an unreduced number of 76 chromosomes, but Meurman (173) and Smith (230) reported it as a normal diploid. As previously pointed out (231), however, it may also conceivably occur in the tetraploid form in nature.

Naturally occurring triploid or approximately triploid forms of three species in the section *Leuce* have been reported in recent years. Nilsson-Ehle (180), Blomqvist (42) and Melander (171) all reported finding strains of a "gigas" triploid ($2n = ca.\ 57$) form of *P. tremula* L. in the forests of Sweden. Later Nilsson-Ehle (181, 182) and Johnsson (138, 139, 142, 143) reported synthesis of triploids, tetraploids and various intermediate aneuploids from artificial triploid × diploid crosses.

Peto (193) has reported occurrence of triploid forms of *P. alba* L. and *P. canescens* (Ait.) Smith in Canada, and Dillewijn (73, 74) reported a naturally occurring form of *P. alba* in the Netherlands.

Diploid and Triploid Species Analysis

Most studies of diploid species (40, 176, 138, 82, 193, 230) reveal that meiosis is for the most part regular. Univalents at metaphase I have, however, been observed in various species by several workers. Smith (230) suggested that univalents observed in *P. laurifolia* and *P. adenopoda* were the result of precocious separation due to failure or early terminalization of chiasmata rather than lack of homology.

Johnsson's (138) study of meiosis in 16 diploid *P. tremula* clones from various provinces in Sweden showed 12 which behaved quite normally, but four showed varying numbers of univalents at metaphase I. Temperature changes in early spring during gametogenesis were suggested as a possible explanation. Pollen sterilities of these clones is shown in Table IV.

Meiosis in natural triploid clones having an unreduced chromosome set of 57 is in general characterized by considerable abnormality (176, 193, 138, 230). Variable numbers of univalents, bivalents and trivalents have been observed, and in one triploid *P. alba* clone studied, quadrivalent associations were noted (230).

TABLE IV

POLLEN STERILITY IN NATURAL DIPLOIDS AND TRIPLOIDS OF *Populus*

Species	*2n chromosome No.*	*Pollen sterility %*	*Authority*
P. acuminata	38	45	Smith (230)
P. adenopoda	38	19	"
P. alba	38	3	"
P. deltoides	38	2	"
P. grandidentata	38	2	"
P. koreana	38	12	"
P. laurifolia	38	40	"
P. nigra	38	3	"
P. nigra italica	38	4	"
P. Sargentii	38	7	"
P. tremuloides	38	2	"
*P. tremula**	38	30	Johnsson (138)
*P. tremula**	38	61	"
*P. tremula**	38	20	"
*P. tremula**	38	33	"
P. alba	57	23	Smith (230)
P. alba var. *aureointertexta*	57	6	Peto (193)
P. tremula	57	56	Müntzing (176)

* Noticeably aberrant individuals from a group of 16 studied.

Müntzing (176) and Smith (230) have concluded that on the basis of pairing relationships displayed at meiosis in the natural triploid forms of diploid species thus far reported, such triploids must be autotriploids resulting from the fusion of a diploid and haploid gamete. Precocious furrowing (230) or spindle fusion during the meiotic divisions (176, 75) may be responsible for the formation of microspores with an unreduced set of chromosomes.

Pollen sterility percentages for various diploid and triploid clones observed by several investigators are shown in Table IV.

The diploid clones, representing typically "pure" species of the genus, show a surprising range in pollen sterility. When these data are compared with chromosome pairing data for the same species (230), there is an obvious correlation between frequency of univalent chromosomes at metaphase I and pollen sterility. Thus in those species where univalents have not been observed, pollen sterility is low, two to seven percent; but in species showing univalents the pollen sterility is markedly higher, 19 to 45 percent. Smith (230), however, concluded that the univalent frequency was too low in these species to account fully for the sterility observed.

Pollen sterility of the several triploid clones which have been studied (Table IV) is remarkably low, in several cases being lower than some of the "pure" diploids. In the opinion of Peto (193) the genetically unbalanced pollen grains undergo early deterioration and consequently are not included in pollen sterility counts. This explanation may be criticized on the basis of Johnsson's (138, 139, 142, 143) and Bergstrom's (35) results which demonstrated that triploid × diploid and triploid × triploid crosses of *P. tremula* yielded progeny with intermediate chromosome numbers, which would seem to imply that in this species, at least, some unbalanced pollen grains are capable of survival.

F_1 Hybrid Analysis

Studies of meiosis in F_1 hybrids of *Populus* have been conducted by Peto (193), Dillewijn (75) and Smith (230). The comprehensive investigations of the last named, involving ten natural and 21 artificial[10] hybrids, revealed that the common meiotic abnormalities encountered were asynapsis which resulted in subsequent lagging of chromosomes at anaphase I and II, inversion bridges caused by structural differences, and various abnormalities in cytokinesis following the second division which gave rise to dyads, triads and microspores in excess of four.

On the basis of Darlington's (63) classification of hybrids, Smith concluded that the interspecific hybrids in *Populus* conform to the class called "undefined structural hybrids", *i.e.*, those resulting from the union of gametes with undefined structural differences between their chromosomes which are either too slight or too numerous to be detected.

In the 31 hybrids investigated by Smith (230), as well as those studied by Peto (193) and Dillewijn (75), univalent chromosomes were present in varying numbers in all. Smith found a close correlation between the occurrence of univalent chromosomes and supernumerary spores. A positive correlation ($r = .88$) was also observed between frequency of univalent formation and pollen sterility. Thus, of the 31 hybrids studied, the highest pollen sterility (80% was observed in X *P. Woobstii* (= *laurifolia* × *tristis*) and the lowest (5%) in the un-named hybrid derived from the double cross: X *P. charkoviensis* × X *P. plantierensis*. In the former case an average of 14.24 univalents per cell were observed, and in the latter case univalents averaged 0.28 per cell.

In practically all of the hybrids studied by Smith, varying numbers of inversion bridges were observed at anaphase I. This is the first report of structural hybridity in the genus, although Dillewijn (75) had previously reported attenuated chromatin strings between anaphase I plates in X *P. robusta*. Smith concluded that pollen sterility in poplar hybrids is probably traceable to genetic, structural and environmental factors, but which exerts the greater influence cannot, on the basis of present evidence, be stated.

Some data of peculiar interest to forest geneticists, reported by Smith (230), concern the influence of age on mutation rate and the possibility that trees or clones of old age may accumulate gene mutations or structural changes in their chromosomes. Theoretically such accumulations in old trees or clones should be detectable by their greater pollen sterility.

In support of this hypothesis it is demonstrated that the 21 artificial hybrid clones of comparatively recent origin (*circa* 1925) that were studied had pollen sterility percentages ranging from five to 40, with an average of 19.7. This, incidentally, corresponds quite closely with the pollen sterility found in the "pure" species studied. The ten natural hybrid clones, however, of much older origin, showed a wider range in sterility (six to 80 percent) and a noticeably higher average of 46.7 percent. Certain of these data are reproduced here without alteration (Table V) from the work of Smith (230).

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[10] Produced by Stout and Schreiner (239).

Speciation

On the basis of his extensive cytological studies of species and hybrids in *Populus,* Smith concluded that species differentiation in this genus has resulted primarily from isolation of a geographic, edaphic and physiological nature. Poplar species are thus examples of "eco-species", as defined by Turesson (261), *i.e.,* uniform types between which crossing is possible with a relatively high degree of fertility, but which commonly are prevented by isolating barriers from doing so.

The evidence in support of this hypothesis is based on the following points:

1. Species of one section cross readily with others under artificial conditions where geographic, edaphic or physiological barriers have been removed.

2. F_1 hybrids of such crosses are relatively fertile; in any case, none is completely sterile. Therefore, in the absence of geographic, edaphic or physiological barriers, backcross generations would permit an exchange of genes between the populations of the two species involved.

3. Although structural and genetic differences, as indicated by inversion bridges and asynapsis, are present in F_1 hybrid chromosomes, the functional fertility of these hybrids discounts genetic or structural chromosomal isolation.

4. Although relatively fertile autotriploid forms of the section *Leuce* occur in nature, they are unable to preserve their identity by sexual means. Numerical chromosomal isolation is thus ruled out as a factor in speciation. (However, if *Populus* is indeed a secondary polyploid it must be conceded that polyploidy played an important part in the ancestral differentiation of the genus.)

TABLE V

A Comparison of Certain Natural and Artificial Interspecific Hybrids of *Populus* in Regard to Date of Origin, Univalent Chromosome Formation and Pollen Sterility (230)

Name or No.	*Parentage*	*Probable date of origin*	*Univalents per cell*	*Percentage of sterility*
Natural hybrids				
X *P. berolinensis*	*P. laurifolia* x *P. n. italica* ...	1870	5.30	57
X *P. canadensis Eugenei*	*P. deltoides* x *P. nigra*	1850	4.92	63
Artificial hybrids				
OP-67*	*P. nigra* x *P. laurifolia*	1925	1.00	16
OP-114*	*P. nigra* x *P. trichocarpa* ..	1925	0.80	23

* Hybrids produced by Stout and Schreiner.

Sex

The dioecious nature of *Populus* has attracted the interest of investigators concerned with the study of sex mechanisms in plants. Blackburn and Harrison (40) first reported an heteromorphic bivalent in male clones of *P. tremula* and *P. nigra.* Meurman (173) also observed an heteromorphic pair in males of several other species and concluded that sex in *Populus* is determined by an XY mechanism similar to that prevailing in most animals.

Subsequent studies by various workers have confirmed these observations or criticized them. Müntzing (176) has pointed out that some intersexual forms should be found in the natural triploids if they originate from the union of haploid and diploid gametes. No such intersexes have been reported. Peto (193) found no consistent evidence of heteromorphic pairs, and Smith (230) was of the same opinion.

A point of considerable theoretical and practical interest to tree breeders interested in the genus *Populus* relates to the possibility that certain secondary sexual characters may distinguish the sexes.

C. S. Larsen (158) has discussed the problem briefly with respect to certain dioecious ligneous genera, citing his own observations and those of various other European botanists. This investigator, for instance, studied natural stands of *Juniperus communis* and found a positive correlation between sex and growth habit independent of site: the female trees being comparatively broad, the males being more slender (156).

The same author (158) has cited the observations of Correns (61) who noted that male specimens of *Ginkgo biloba* and *Taxus baccata* are on the average larger; and, with reference to the ginkgo, Grier (94) has also reported an apparent correlation between sex and growth habit.

Houtzagers (120), with reference to the ash planted in Holland, says: . . . "of this species (*Fraxinus excelsior* L.)—which, however, is not purely unisexual and dioecious—the male specimens generally grow better and straighter than the female specimens do".

Evidence of the occurrence of secondary sex characters in poplars is confined for the most part to cultivated forms, little attention having yet been directed by silviculturists or geneticists to the analysis of natural stands. In the case of the widely planted ornamental variety of the black poplar, Lombardy poplar (*P. nigra italica* Muench.), it is the male form which is most favored by horticulturists. This preference is undoubtedly traceable to the markedly columnar habit of this sex, the females having a broader crown.

Larsen (158) reported sexing of an ornamental planting of grey poplar (*P. canescens* (Ait.) Sm.) in Denmark and found only "male individuals with the exception of a single female tree, which differed much from the others in being considerably smaller and of another shape of crown". The same author (158) has pointed out that early cultivation of *P. trichocarpa* in Sweden was attended with good results, whereas plantings of the same species in the State of Anhalt, Germany, were less satisfactory. It has been suggested that the explanation might be that in the former case it was a male clone which had been introduced, and in the latter case a female.

Other less specific evidence may be cited which is suggestive of sexual dimorphism in the genus. It is of interest, for instance, to note that of the eight commonly planted poplar clones in Holland, as listed and described by Houtzagers (116), only two (25%) are females.[11] A preference for males in this case may, however, be traceable to the fact that the "cotton" is irritating to the nostrils of cattle, and Dutch farmers may thus discriminate against female trees.

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[11] Clones of both sexes of the native *P. nigra* L. are apparently planted without preference as to sex, and consequently this species is not here included. Of the eight forms considered, four are represented exclusively as male clones and two are "chiefly male, though some female trees are found".

Analysis of data on the sex of a number of poplar clones selected in the fall of 1947 by the present author (188) in collaboration with Dr. Helge Johnsson of the Swedish Forest Tree Breeding Institute, Ekebo, Källstorp, Sweden, reveals that out of 76 clones (including *tremuloides, grandidentata, tacamahaca, trichocarpa* and *deltoides*) bearing flower buds, only 18 (23.7%) proved to be females. Since the trees were selected on the basis of their apparent health, vigor and good stem form as compared with their associates in various stands throughout the United States and Canada, it might be concluded tentatively that a positive correlation exists in this genus between maleness and these desirable economic characters.

Such a conclusion is, however, confounded by the empirical observations of Baker (26) with respect to the apparent sex ratio in aspen stands of the central Rocky Mountains. This worker noted that "the staminate trees are much more frequently found than the pistillate, which are very rare indeed", and Williamson (289) makes a similar observation with regard to the cottonwood stands of the Mississippi valley. If such aberrant sex ratios are indeed characteristic of natural stands, it is apparent that samples of wild populations such as noted above cannot in themselves be used as evidence of male superiority. But if a sex mechanism for *Populus* is postulated that would theoretically result in a 1 : 1 ratio of the sexes, we must conclude that the presumed aberrancy of such ratios in favor of males in nature must be traceable to some sex-associated survival factors such as vigor, disease resistance and hardiness.

Although the evidence at present available is in no way conclusive, it is at least strongly suggestive that sexual differences within the genus do exist, and that such important characters as growth habit, stem form, disease resistance and vigor appear to be associated with the male sex. It is needless to point out that such a correlation, if confirmed, would be an invaluable aid to the selection efforts of tree breeders and silviculturists interested in the genus *Populus*.

Summary

Except for one tropical species in east Africa, *Populus* is native of the north temperate zones of Europe, Asia and North America. Of the approximately 30 species now known, only four are native in Europe and western Asia, the remainder being about equally divided between North America and eastern Asia.

Classification and nomenclature in the genus are confused and inadequate to describe the wide range of variability which has accumulated chiefly through ecotypic isolation and natural and artificial hybridization. This situation has led to interminable confusion in the literature. The only adequate solution appears to be an internationally cooperative agreement on nomenclature which will be based on a system of clonal names or numbers.

Studies of wild variability as a means of selecting superior forms for direct use or as parents for progeny tests and further breeding has been given considerable attention in Europe. In North America and Asia, however, very little work has been directed to this basic problem.

Much effort has been expended in the process of performing interspecific crosses, especially with species of the sections *Leuce, Tacamahaca* and *Aegeiros*. These studies have revealed a wide range of compatibilities, and suggest promising combinations for more intensive work in the future. It may be anticipated that such future studies will be more critically concerned with the genetic quality of the individual parents concerned than has been the practice heretofore. It appears likely that the valuable North American and Asiatic species of the section *Leuce*, early discriminated against and essentially ignored because of their reputation as poor rooters, will attract more interest from tree breeders.

Very little intraspecific hybridization has been carried on within the North American and Asiatic poplars, but on the basis of German and Swedish results in this field such investigations hold promise of yielding valuable results.

Rather extensive cytological studies have been conducted by a number of workers in *Populus*. Representatives of most species and many hybrids have been examined, but the sampling of wild populations outside of Europe has been very inadequate. The diploid number of chromosomes for most individuals of the various species examined is 38, but natural triploid forms are of relatively common occurrence in the European species of the section *Leuce*. There seems to be little doubt that triploidy is the natural limit of heteroploidy in the genus.

Most poplar hybrids display a comparatively high degree of fertility, and primarily on the basis of this fact it has been postulated that edaphic, geographic and physiological isolating mechanisms have been chiefly concerned with the process of speciation in the genus.

Some empirical observations are assembled by the author which suggest that a positive correlation may exist between maleness and such economically desirable characters as vigor, disease resistance and good stem form in the poplars.

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Correction

ECONOMIC BOTANY, Vol. 2, page 107, para. 2, requires correction, since the work of Tschermak in 1918 on heterosis in tomatoes referred to there is antedated by that of R. Wellington reported in New York Agr. Exp. Sta. Bull. 346, 1912, and by that of H. K. Hayes and D. F. Jones in the Annual Report, Conn. Agr. Exp. Sta., 1916. Professor Tschermak, who, of the three rediscoverers of Mendel's principles, alone survives, writes that he probably was one of the first to obtain tentative evidence of heterosis in tomatoes and that his successor, Professor Dr. Fr. Frimmel, published evidence confirming it in Zeits. Pflanzenzüchtung **10**: 453–466. 1924–25.—J. W. Lesley.

Utilization Abstract

Waxes and Fats from Sugar Cane. In 1940, 26 million pounds of vegetable waxes were imported into the United States, and from January through September of 1947 such imports consisted of 8,444,000 pounds of carnauba, 8,371,000 pounds of candellila and 1,637,000 pounds of ouricouri, the three most important commercial waxes. [Carnauba wax is scraped from the leaves of *Copernicia cerifera,* a palm tree native to Brazil and other parts of tropical South America; candelilla wax is removed by hot water or solvents from the stems of *Pedilanthus Pavonis* and *Euphorbia antisyphilitica,* desert shrubs of Mexico and Texas; and ouricouri is similarly obtained from the leaves of *Cocos coronata,* a species of palm in northeastern Brazil.

Annual world production of vegetable waxes amounts to about 35 million pounds, approximately 80% of which is consumed in the United States in the manufacture of waxes for floors, shoes, furniture, automobiles, boats and aircraft, and in other items, including carbon paper and printing inks, textile water repellents and fruit and vegetable coatings, moulding compositions and phonograph records, and a score of less important products.

The many industrial uses of waxes have led to a search for other sources, and attention is now being directed to the possibilities of commercial production of wax from sugar cane.

"Interest in sugar cane wax dates from the early years of the twentieth century. The first wax-recovery plant, established in 1916 in Natal, Union of South Africa, obtained the wax from sugar factory press cake by solvent extraction methods. Thousands of tons of wax were produced during its ten-year period of operation. The operations ceased, apparently, when normal distribution and prices of the usual commercial waxes were re-established after World War I. But due to the scarcity of vegetable waxes during World War II and the post-war high costs, the interest in sugar cane wax has again revived. Not long ago the Cuban American Sugar Company and S. C. Johnson & Son, Inc., built a plant for the extraction of crude sugar cane wax from press cake at the Cuban American Sugar Company's plant in Cuba and have been producing sugar cane wax in commercial quantities for over a year."

This cuticle wax is obtained from the press cake of sugar cane, after extraction of sugar, and varies from 1% to 22% by dry weight of the cake. The crude wax is extractable by a number of solvents, including benzene, methyl and rectified spirits, acetone, certain esters, numerous aromatic hydrocarbons and petroleum solvents, and liquid sulphur dioxide and petroleum naphtha. After filtration or other means to obtain a clear extract, the crude wax is attained by evaporation of the solvent. (R. T. Balch, *Chemurgic Digest 7(7): 11. 1948*).

ECONOMIC BOTANY

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VOL. 3 OCTOBER–DECEMBER No. 4

Semi-Popular Articles

HISTORY, TAXONOMY AND CULTURE OF THE PINEAPPLE. *J. L. Collins* 335
MYCOLOGICAL PRODUCTION OF CITRIC ACID—THE SUBMERGED CULTURE METHOD. *D. Perlman* 360
RESEARCH ON THE IMPROVEMENT OF TURPENTINE PRACTICES. *Albert G. Snow, Jr.* 375
FIBER FLAX IN OREGON. *Donald W. Fishler* 395
THE ESSENTIAL OIL OF *Pectis papposa*. *C. E. Bradley and A. J. Haagen-Smit* 407
PROBLEMS ASSOCIATED WITH THE PROCUREMENT OF PLANT PRODUCTS FROM THE AMERICAN TROPICS. *Robert W. Schery* 413
IRISH MOSS—A SEAWEED THAT SUPPORTS AN INDUSTRY. *Leonard Stoloff* 428

Utilization Abstracts

By the editor

Page 359—Flax. *Page 374*—Citrus Waste Oil. *Page 394*—Rutin. *Page 406*—Carob. Papaya. *Page 412*—Rice Hulls. *Page 427*—Tall Oil. Safflower. Herculin. *Page 436*—Indigenous Food Plants of West Africa. *Page 444*—Tropical Woods.

History, Taxonomy and Culture of the Pineapple

Pineapples, native to tropical America, have been most extensively produced in Hawaii which accounted for 85% of the 12¼ million cases of canned pineapple produced in 1947 by all countries of the world.

J. L. COLLINS
Pineapple Research Institute of Hawaii

Early History

THE pineapple is a native American plant first seen by people from the Old World when Columbus and some of his sailors landed on the island of Guadeloupe on November 4, 1493, on his second voyage to the New World. This island, to which Columbus gave the name it still bears, is in the Lesser Antilles of the West Indies and is located about 16° north of the equator.

At the time that America was discovered the pineapple appears to have been well distributed throughout most of tropical America with the possible exception of the West Coast of South America. In many places evidences were found by the early explorers of its cultivation by the Indians. These pineapples included several distinct varieties, all of which were seedless or nearly so, although wild pineapple species growing in some parts of the American tropics were extremely seedy. It thus appears that some selection and improvement of the pineapple had been accomplished by the Indians or their predecessors in order to produce and preserve these more useful varieties.

De Oviedo, who came to the New World as a Spanish government official in 1513, was, we believe, the first to furnish a written description of some of these different forms. In his history of the Indies he gives a brief description of three varieties together with the Indian names for them.

Besides using the fruit for food the Indians had also learned to make a wine from pineapples. This practice of wine-making was well distributed throughout the country, for it is mentioned by several writers, including Columbus, Oviedo and Sir Walter Raleigh.

Apparently the Indians had also developed a belief in certain medicinal qualities of the pineapple because the early voyagers and settlers often wrote of the value of the pineapple in the treatment of certain human disorders. Such beliefs could hardly have been developed independently by the Europeans in so short a time of acquaintance with the fruit. For instance, we have the following statements in the early literature dealing with the medicinal qualities of the pineapple:

"Some condemn it for biliousness. I am not certain about this. I do know that it rouses the appetite. There are many people who have lost the desire for food. It restores a healthy appetite and stimulates them to try to eat, restoring enjoyment".

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[1] Published with the approval of the director as Miscellaneous Paper No. 47 of the Pineapple Research Institute, University of Hawaii.

This account of the effect of pineapples on rousing the appetite was written by Oviedo only about 25 years after the discovery of America and was probably learned from the Indians. More than usual interest is attached to this statement because 425 years later a scientifically conducted experiment at a State experiment station revealed that animals given a diet including pineapple ate and utilized more food than a similar group not having pineapple in their diet. This was interpreted to mean that their appetites had been stimulated by the pineapple.

In 1658 another early historian[2] made a similar statement when he reported that the fruit is admirable for recovering the spirits and was employed for correcting disorders of the stomach. Modern research has shown that the pineapple fruit contains the enzyme bromelin which does aid in the digestion of proteins.

Again in Sloane's "Natural History of Jamaica" (London, 1707) we find Piso credited with the statement that ". . . It is a great cordial to fainting spirits and helps a squeamish stomach. Its juice and wine is good for the suppression of urine . . . as also against poisons especially cassada". We do not have modern information relative to these latter claims.

The Portuguese appear to have played a major role in carrying the pineapple to other tropical countries. The island of St. Helena was discovered by them in 1502, and very soon afterward they introduced pineapples to this island. They also carried it to the west and east coasts of Africa and to Madagascar at an early date. About 1550 they were responsible for its introduction into southern India.

Before the close of the 16th century it had also become established in China, Java and the Philippines. In 1591 a missionary in the Philippines reported that the natives there made a fine type of cloth from the fibers of pineapple leaves.

We believe that some of this transportation to other areas was incidental to the use of the pineapple as an item of food for the crews on these long sea voyages in the sailing vessels of that period. Pineapples were available in many American places where these vessels outfitted with food and water for continued exploration expeditions or return voyages. Crowns from fruits used during a voyage or when at anchor in a new port were thrown overboard and washed ashore or intentionally carried ashore for planting. Because of the unique ability of pineapple crowns and slips to remain viable during long periods of drought they would be able to survive and establish themselves under just such conditions as these postulated.

There are very few records to show exactly when or how pineapples first arrived in these new lands. The origin of pineapples in Hawaii is a good example of the lack of exact knowledge of its introduction to other countries. There exists a form on the island of Hawaii which has been growing there for as long as the oldest inhabitants can remember, but its origin and manner of arrival are unknown. The Hawaiian people gave it the name "halakahiki", which means, in their language, the hala from a foreign land. The hala, *Pandanus odoratissimus*, a native Hawaiian plant with which the indigenous people were well acquainted, has a fruit somewhat resembling that of the pineapple.

Taxonomy, Morphology and Ecology

The species of the family Bromeliaceae, to which the pineapple belongs, are with one exception indigenous to tropical and sub-tropical America. This one exception is native to the West Coast of Africa. Spanish moss (*Tillandsia usneoides*), a common sight in some of our southern States, is an epiphyte belonging to the pineapple family. The family includes both terrestrial and epiphytic types.

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[2] Rochefort, C. de, Histoire Naturelle et Morale des Iles Antilles de l'Amerique. 1658.

The pineapple is in the terrestrial group, although it is reported to have mycorrhizae on the roots in the axils of the water-holding leaf bases. Mycorrhizae are characteristic of some of the epiphytic types of the family. They are very fine filaments of fungi, closely associated with the roots and probably assisting in nutrition. Such fungi are well known in many groups of plants, and in orchids they are essential for proper development of seedlings.

Botanists have not always agreed as to the botanical classification of the different pineapple forms, and there is still some difference of opinion. The classification now generally accepted in this country is that of L. B. Smith (Harvard Univ., Bot. Mus. Lft. 7(5). 1939), which recognizes four species in the genus *Ananas* and one in the closely related genus *Pseudananas*. Both genera have collective fruits which serve to separate them from most other genera of the Bromeliaceae. They can readily be distinguished on the basis of five rather distinct characters which are listed in Table 1.

TABLE 1

PRINCIPAL DIFFERENCES BETWEEN *Ananas* AND *Pseudananas*.

Characters	*Genera*	
	Ananas	*Pseudananas*
1. Crowns on fruit	Present	Absent
2. Slips on peduncle	Present	Absent
3. Stolons	Absent	Present
4. Petal appendage	Funnel-like scale present	Absent
5. Chromosome number	50	100

Pseudananas macrodontes (E. Morr.) Harms is a wild species found along the Paraná and the Paraguay Rivers in northern Argentina, Paraguay and southwestern Brazil. It appears to be limited almost entirely to shaded areas in open woods or brush land which is subject to periodic flooding or heavy rainfall for part of the year. It is also able to withstand long periods of drought. *Macrodontes* is the only species in this genus, and it appears to have no distinct varietal forms, such as are known for three of the species of *Ananas*. Some of the characters of *macrodontes* suggest that it may have originated from hybridization between two genera, *Ananas* and *Bromelia*, following by doubling of the chromosome number of the F_1 hybrid. No genetic evidence for this hypothesis has been obtained other than the production of fertile hybrids between *Ananas* and *Pseudananas*. Attempts to produce hybrids between *Pseudananas* and *Bromelia*, the other suggested parent form, have so far failed to produce offspring.

The genus *Ananas* includes three species of wild pineapples—*bracteatus* (Lindl.) Schultes, *ananassoides* (Bak.) L. B. Smith and *erectifolius* L. B. Smith —together with *comosus* (L.) Merr. which includes the cultivated varieties of pineapple.

The major specific differences within the genus *Ananas* are listed in the following brief description of the more conspicuous characters together with a discussion of the natural habitats.

Ananas bracteatus. This species is conspicuous for the brilliantly colored pink-to-red bracts, 1 to 1½ inches long,

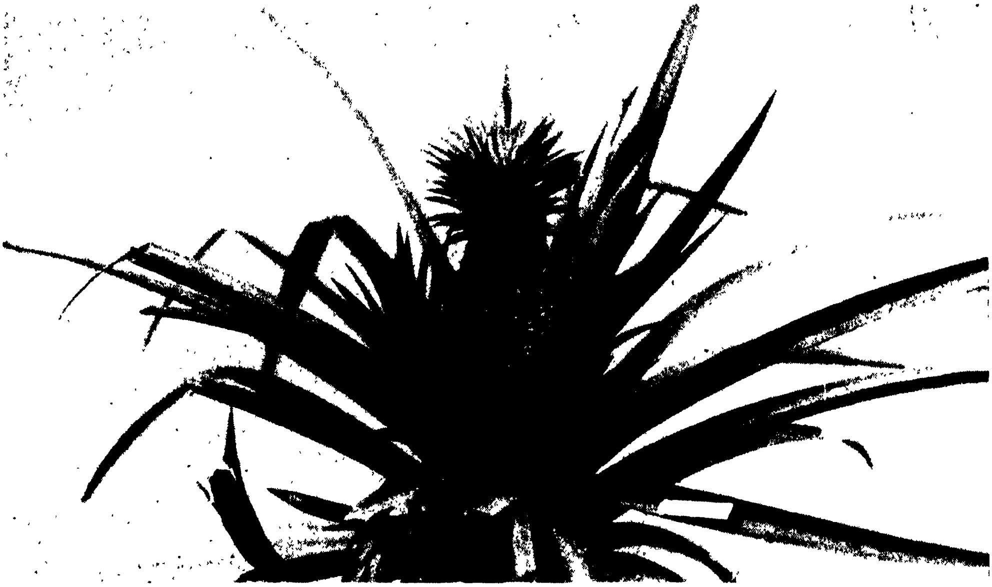


FIG. 1 (*Upper*). A pineapple plant with leaves attached to the stump, showing a nearly mature fruit, one slip on the right at the base of the fruit, one sucker on the left and a second sucker behind the fruit.

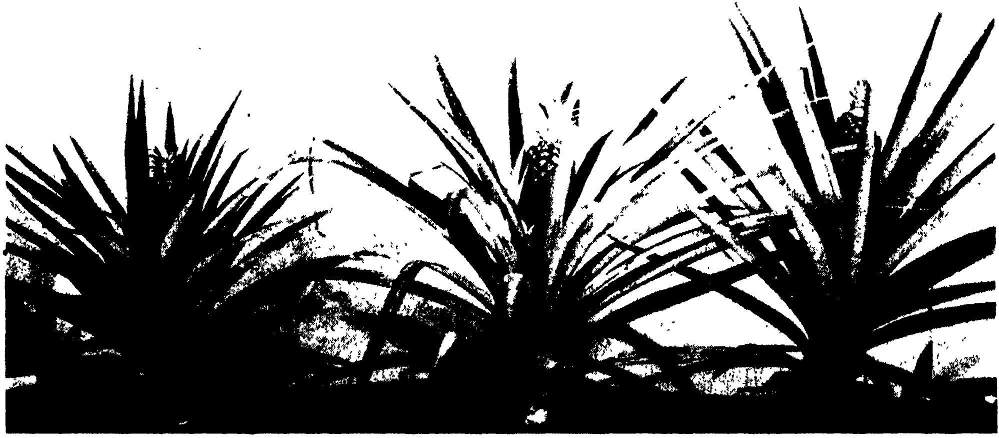


FIG. 2 (*Lower*). Somatic mutations occasionally arise in vegetatively propagated varieties. The Cayenne variety has produced about 45 known types. Here normal Cayenne in the middle is flanked by two mutations. The plant on the left has shorter but more numerous leaves; on the right, longer, fewer, less recurved leaves. The latter is also two weeks later in producing ripe fruit.

subtending individual florets on the fruit, and the pink sterile bracts at the base of the fruit. The fruits lose this conspicuous color to a large extent at maturity, but the long bracts remain a characteristic feature. Numerous slips are produced on the peduncle at the base of the fruit and frequently at the base of the crown on top of the fruit. Fruits and slips are borne on a tall peduncle which frequently bends over due to the weight of the fruit. Fruits are seedy, flesh whitish and usually more porous than in well cultured fruits of *comosus*.

This species occurs in three areas of South America and probably is present also in some of the intervening territory. These areas are: first, the central coastal region of Brazil in the State of Pernambuco; second, the Rio de Janeiro and São Paulo regions; third, the Paraná River valley from around Posadas in northern Argentina up the Paraná almost to the northern limit of Paraguay.

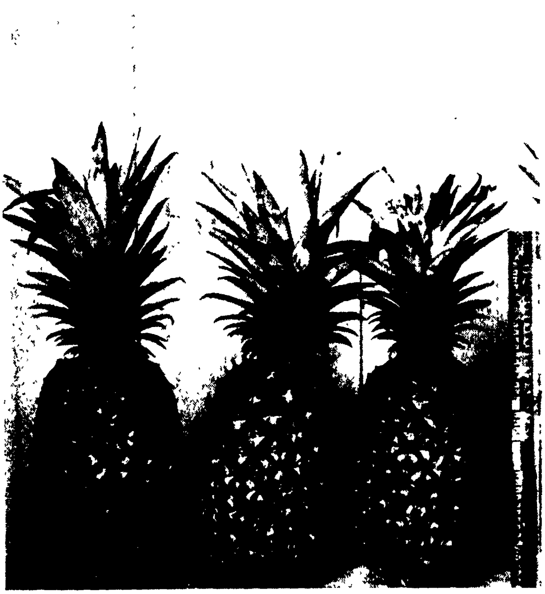


FIG. 3 (*Left*). Average sized fruits of the Cayenne variety which supplies about 90 percent of the canned pineapple of the world.

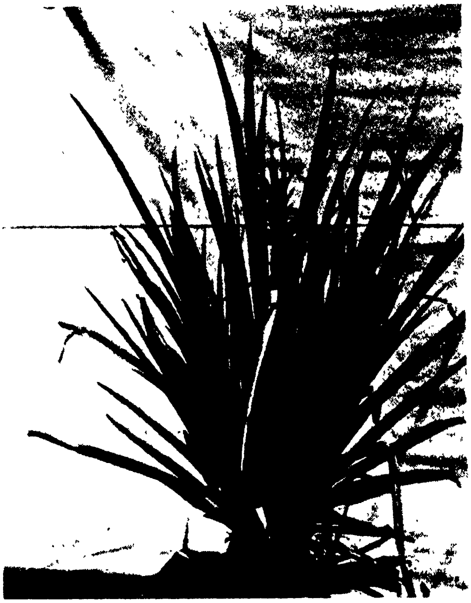


FIG. 4 (*Right*). *Ananas erectifolius*, a wild species of pineapple having spineless leaves and a small edible fruit on a long peduncle. This species was at one time cultivated in British Guiana for the fiber of its leaves.

This species has almost always been found in proximity to habitations or where habitations formerly existed. This suggests that it may have been spread and maintained by man, and that its present distribution does not represent its original native area. Only in the southern part of Paraguay has this species been cultivated in recent times, as far as we know, and here only in a single small plantation. The fruits are not considered edible by ordinary standards.

Ananas ananassoides has long, narrow, recurving (¾ to 1¼ inches wide, 2 to 4 feet long), very spiny leaves, with a small fruit (3 to 5 inches long, 1½ to 2 inches wide) borne on a tall slender peduncle which holds the small fruit well above the rosette of leaves. The fruit is very seedy, with a tough, fibrous texture. There are several varieties, only one of which has been named. The type form of the species does not produce slips on the peduncle, but some of the varietal forms do, including the small dwarf form, *nanus*. This dwarf form grows wild in the central Matto Grosso region of Brazil near Aqui-

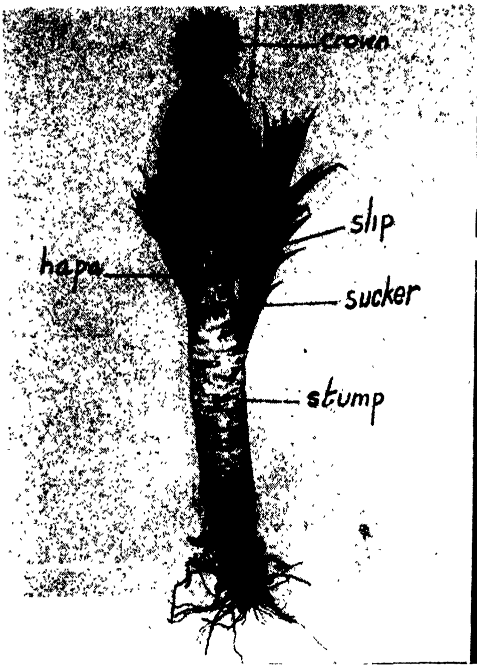


FIG. 5 (*Left*). A fruiting pineapple plant with leaves removed to show stump and the attachment of slips, hapas and suckers.

Fig. 6 (*Right*). *Ananas ananassoides*, wild pineapple, from Brazil, growing under cultivation. (*Photo by M. B. Linford*)

dauana and is also used as an ornamental potted plant in some of the coastal cities of Brazil.

A. ananassoides is the most widely distributed of the wild pineapple species. Its area extends from the coastal region of Brazil around São Paulo northward to and into southern Matto Grosso and northern Paraguay. It probably also extends northward in central Brazil until stopped by the Amazonian jungle. This species represents the highest development for drought resistance in the genus and is found in the poorer and dryer soil areas along with other semi-arid types of plants.

Ananas erectifolius is a species set apart from the others most conspicuously by its erect type of leaf growth and the almost absence of spines along the leaf margins. The small fruit borne on a tall peduncle, distinctly thicker than in *A. ananassoides*, is cylindrical in shape and 2½ to 3 inches high, with a diameter of about two inches. Slips are produced at both the base and top of the fruit. The long slender leaves lack anthocyanin pigment. The fruit is only sparsely seedy.

Not much is known about the extent of its natural habitat, but it is believed to be the valley of the main Amazon river. It, therefore, occurs in a low, humid, hot environment quite different from that typical of *A. ananassoides*. However, this species grows well when transplanted to less extreme tropical regions. The fruit is not considered to be edible; however, the species was at one time cultivated in the Amazon valley for the fiber of its long, slender, spineless leaves.

Thus the four wild species, including P. *macrodontes*, represent a range of natural habitats from the hot humid lowlands of the Amazon valley to the semiarid high plateau areas of central Brazil and northern Paraguay.

Ananas comosus Merr. This species ncludes the cultivated varieties of the genus and would, by some people, be listed as a cultigen, since all members of it are cultivated types, with no recognizable wild ancestral form. As already mentioned, varieties of this species were being cultivated by the Indians when America was discovered and had been well distributed through tropical America by the Indians in pre-Columbian times. Forms of this species have been found growing in a wild state, but they are believed to be escapes from places of former cultivation.

The primary characters separating *comosus* from the three wild species of the genus may be listed as follows. First, the fruits are usually but not always larger and they contain a relatively large amount of palatable flesh. Second, the fruits are seedless or only rarely produce a few seeds. Third, the floral bracts are quite inconspicuous in the mature fruit and do not cover the top of the ovary. Fourth, the peduncle is usually thicker than in the wild species.

Chromosome Numbers

The basic haploid chromosome number in *Ananas* appears to be 25 for all species.

Triploids having 75 chromosomes have been reported for three *comosus* varieties: one from Brazil, one from Ecuador and one from the West Indies. The last is the Cabezona variety grown to a limited extent in Florida and Cuba.

Numerous tetraploids with 100 chromosomes and triploids with 75 chromosomes have been produced in conection with plant breeding work in Hawaii. These polyploids show the characters of giantism and extended vegetative growth period usually found in induced polyploids.

The varieties of *A. comosus* are self-incompatible and hence are seedless when self-pollinated. However, crossing between varieties usually produces abundance of viable seed. Likewise, crosses between *comosus* and the wild species produce viable seed and vigorous F_1 plants.

All possible crosses between species have not been reported, but those which have been made (Table 2) have produced vigorous fertile F_1 hybrids. The wild self-fertile species appear to be approximately homozygous genetically, but the varieties of *A. comosus*, on the other hand, are highly heterozygous. Genetic studies from species hybrids have shown that the species have a number of homologous genes.

TABLE 2

CROSS COMPATABILITY BETWEEN SPECIES OF PINEAPPLE

Species used in crossing	*comosus*	*ananassoides*	*erectifolius*	*bracteatus*	*macrodontes*
*comosus**	+				
ananassoides	+	+			
erectifolius	+	−	+		
bracteatus	+	+	+	+	
macrodontes	+	−	+	−	+

* It should be noted that *comosus* varieties are self-incompatible, but most others are cross-compatible. The other species are all self fertile. The interspecific crosses obtained would indicate complete interspecific compatibility. The + indicates compatibility of the indicated cross.

Plant and Fruit

Some of the early Spanish explorers described the pineapple as being somewhat like an artichoke or a thistle. In its general appearance, however, it is much more like a lily plant, an agave or

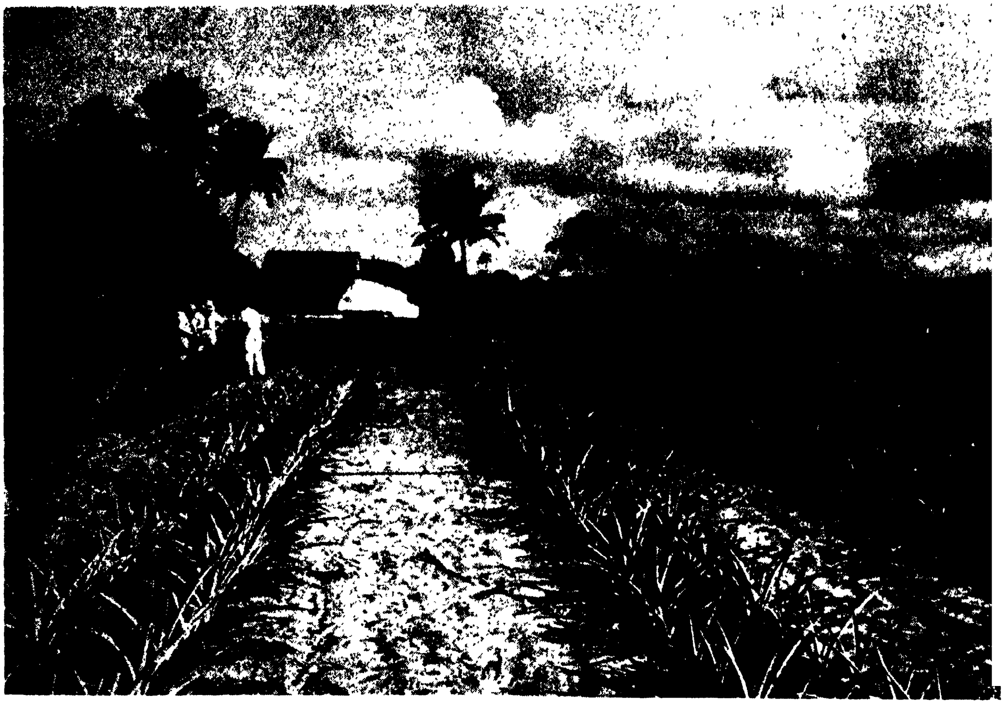


FIG. 7 (*Upper*). Pineapple field in the State of Pernambuco, Brazil, showing method of planting without mulch paper and about eight feet between plant beds. Compare with the 28 to 30 inches between beds in Hawaii.

FIG. 8 (*Lower*). Wild pineapple species, *Ananas ananassoides*, in natural habitat in the Matto Grosso of Brazil.

even some of the yuccas than it is like either of the two they mentioned.

The plant is a biennial, producing a group of parallel veined leaves, 30 to 40 inches long and 2 1/2 inches wide, tapering to a point at the free end. The edges of the leaves are spiny in some varieties, while in others the spines are absent. The leaves are borne so close together that the leaf bases overlap each other where they clasp the cylindrical main axis.

During the first year the plant stores up starch in the thick central axis for production of the inflorescence. Differentiation usually occurs in the early part of the winter, but the bud is not visible until about three months later. Experiments have shown that a drop of about 10° F. mean night temperature during the winter months is probably the primary environmental factor causing the change from a leaf-producing apical stem meristem to a flower-forming meristem. Differences in length of daylight in latitudes where pineapples grow have little if any influence in flower production. The inflorescence is borne at the top of the plant axis and terminates the length growth of the plant. The fruit is mature in six to seven months after differentiation. On the peduncle below the fruit are produced the small shoots known as "slips", and from some of the leaf axils on the main stem are produced other shoots known as "suckers" or "ratoons". These constitute the generally used parts for propagation. The core of the fruit is a continuation of the peduncle, and at the top of the fruit produces the vegetative shoot known as the "crown". This is also sometimes used for propagation.

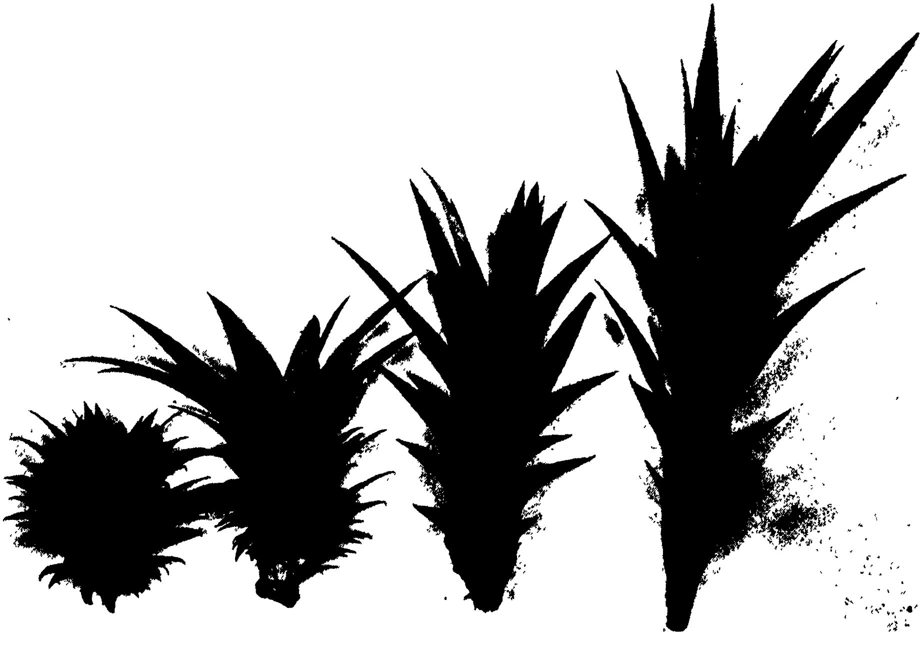
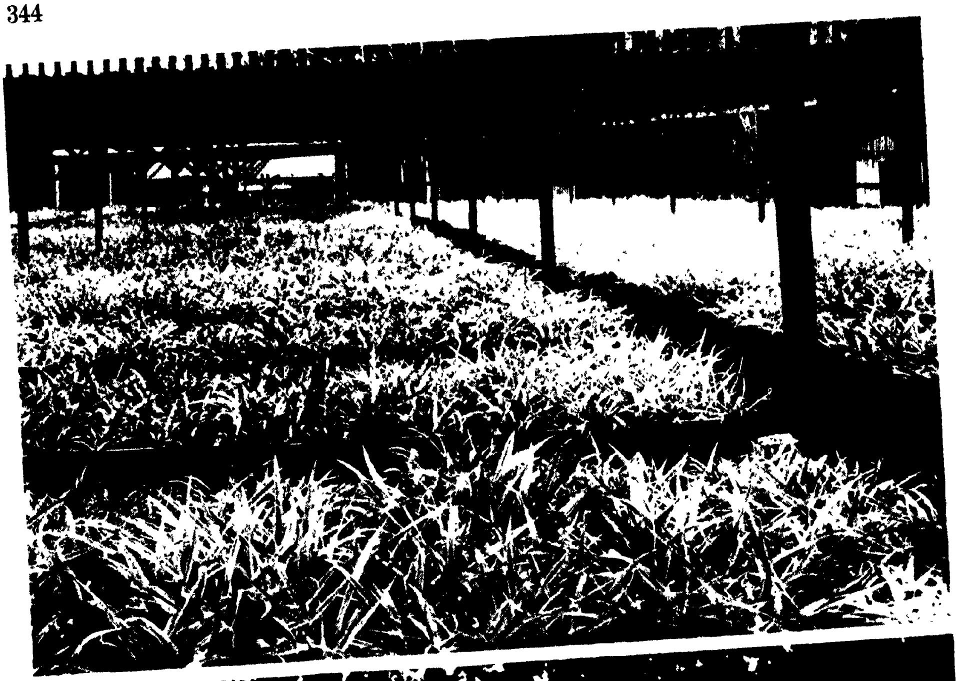


FIG. 9. The types of asexual planting material used in propagation of pineapples. Left to right: crown, slip, hapa and sucker.

The pineapple fruit is collectively



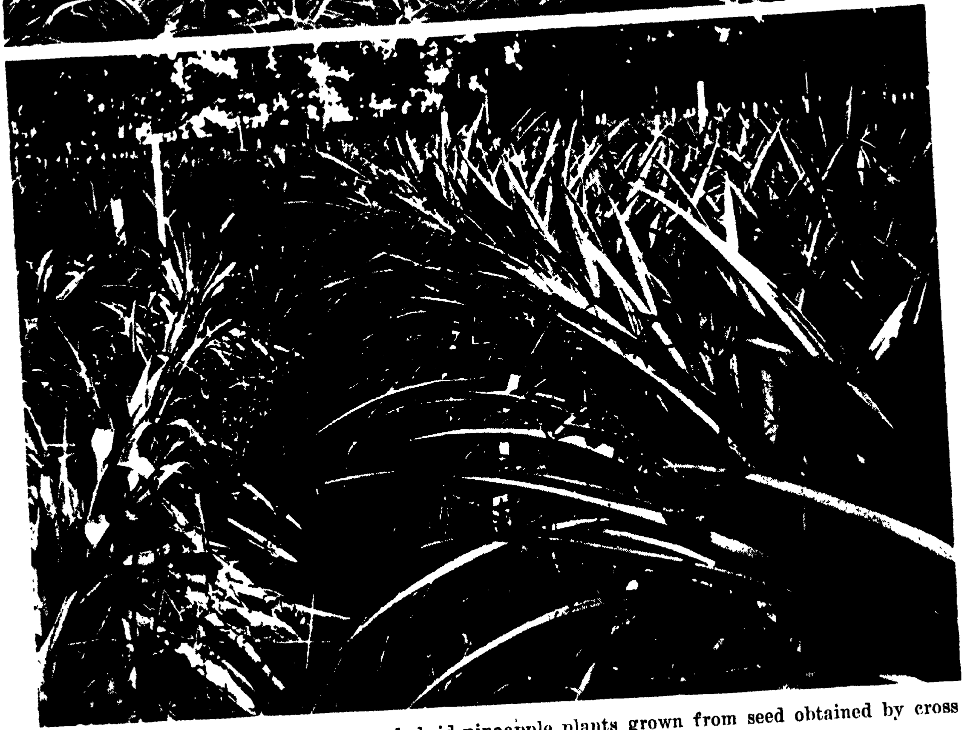


FIG. 10 (*Upper*). 70,000 young hybrid pineapple plants grown from seed obtained by cross pollination of varieties and species.

FIG. 11 (*Lower*). A mealybug wilt-susceptible variety (left) and a wilt-resistant hybrid (right).

made up of a number of individual berry-like fruitlets, each attached to the central axis core, and fused throughout its length to adjacent fruitlets. The fruitlets are arranged spirally in an 8/21 phyllotaxy in the larger-fruited varieties of *A. comosus.* The number of fruitlets varies with size of the fruit from around 110 to 180 for the Cayenne variety. Smaller-fruited species like *A. ananassoides* have a 5/13 phyllotaxy and a lower number of fruitlets. The shell of the collective fruit is made up of the three thickened fleshy sepals and the fleshy bract partially covering the sepals of each fruitlet. These flattened fleshy sepals are weakly fused at their outer margins with the sepals of adjacent fruitlets, forming a continuous rind over the entire fruit.

The individual flowers, in addition to the parts mentioned above, each have three purplish-blue petals, six stamens and a three lobed stigma. The ovary has three carpels, each containing from 10 to 15 ovules.

In the cultivated varieties[3] seedlessness is due to self incompatibility which is not present in the seed-producing wild species. Viable seed can be produced in these seedless varieties by artificial cross pollination. In tropical countries where hummingbirds are prevalent these cultivated varieties frequently produce seeds, but very rarely do so in countries where they are not present, and it is believed that hummingbirds constitute one of the principal means of natural cross pollination. The flowers open in the late morning (8:00 to 9:00 a.m. generally) and close before sunset. The flowering progresses from the oldest florets at the base of the inflorescence to the later formed ones at the apex. This progressive flowering continues for about 20 days, with only a few flowers opening each day.

Commercial Varieties

During its long period of cultivation *A. comosus* has produced a large number of varieties, showing a wide range of variation in a number of characters. Only a few of these varieties have been widely and continuously cultivated. Three varieties, Cayenne, Red Spanish and Queen, are outstanding in this respect. The Cayenne variety has the largest acreage in cultivation and is used almost exclusively in Hawaii and to a considerable extent in Australia, the Philippines and South Africa, with smaller plantings in a number of other countries. The Red Spanish is the dominant variety in Florida, Mexico and the West Indies, while Queen is produced commercially in Australia, South Africa and the Malay Peninsula. The last mentioned is probably the oldest named variety of pineapple still in existence, having been noted in 1658 by de Rochefort and by Evelyn in England in 1661. Whether the present Queen variety is the same as that of these early records, we, of course, do not know.

The Cayenne variety is over 100 years old, probably originating early in 1800, although its name does not appear in the literature until 1841 when it is mentioned as a hot-house variety in England. This variety has almost spineless leaves, and for that reason is generally called "Smooth Cayenne". Genetically it is heterozygous for the recessive spiny leaved character and frequently mutates to the homozygous recessive spiny leaved genotype, thus producing spiny plants which are identical with the smooth-leaved in other respects. This is an undesirable character and is continuously rogued out of commercial fields. Because of this high rate of mutation (1 to 5 percent) it is necessary to discard spiny-leaved planting material each year to maintain relatively pure stands of the smooth-leaved form.

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[3] The Cabezona variety grown in Florida and the West Indies is a triploid having 75 chromosomes and does not produce functional germ cells.

Cayenne with an average fruit weight of about five pounds is the heaviest producing of the three varieties. The triploid, Cabezona, however, usually produces larger fruits than does Cayenne. The flesh of the ripe Cayenne fruit varies in color from pale yellow to yellow, is high in acid and sugars and is essentially a canning type. With the rapid increase in commercial canning of pineapples in Mexico this variety is becoming the dominant one, surpassing Red Spanish.

Queen, on the other hand, is a dual purpose fruit, being used for both canning and a fresh fruit type. The plants have spiny leaves, are smaller in size than Cayenne, and produce small fruits from two to three pounds in weight. These fruits have a golden yellow color, are less juicy and give the general impression of being sweeter than the larger Cayenne. Because of this, they are favored in some countries as fresh fruit.

The Red Spanish variety is quite distinct from the other two. Its fruits are intermediate in size, the flesh is white, quite acid and contains less sugar than the other two. The leaves are semi-spiny or spiny. Most of the fruit goes onto the market as fresh fruit, very little of it being canned, although some of it is used for the production of candied fruit.

Pernambuco is a variety popular in northern Brazil where it is used almost entirely for the fresh fruit trade. It has a very tender, mild flavored, pale yellow flesh which is very pleasing. The fruits are small, and range from 2.5 to 4 pounds. The leaves are spiny.

The Monte Lirio variety is grown in Mexico and Central America. There are no spines on the leaves, and the fruit has a tender white flesh with very pleasant flavor and aroma.

Table 3 gives a comparison of these two minor varieties with the three more widely used ones.

TABLE 3

COMPARISON OF FIVE MAJOR VARIETIES FOR THREE CHARACTERS IMPORTANT IN COMMERCIAL PRODUCTION

	Average as determined in Hawaii		
Variety	*Fruit weight lbs.*	*Sugar as degrees Brix*	*Acid as % citric*
Cayenne	5.5	15.5	0.80
Red Spanish	4.0	13.5	0.68
Queen	2.5	17.0	0.80
Pernambuco	3.0	12.0	0.35
Monte Lirio	3.5	14.0	0.80

Cultural Methods

All or mostly all varieties of *Ananas comosus* produce seedless fruits, and propagation of successive crops is through the use of three kinds of vegetative parts, namely, the slips borne on the peduncle beneath the fruit, the crown borne on the top of the fruit and suckers grown from the leaf axils on the main stem of the plant. The suckers are removed from the plants after fruiting and allowed to dry from one to several weeks before planting. This period of drying prevents rotting of the new plant pieces after planting. The number of planting pieces varies with varieties and growth conditions of the plants, vigorous well cultured plants producing both more and better planting material than poorly cultured ones. In the Cayenne variety the average number per plant is four, while for Red Spanish, Pernambuco and Queen the number is somewhat higher.

The following discussion of cultural methods refers primarily to those used in the large scale plantings in Hawaii, with mention of some practices in other countries. The cultural methods vary

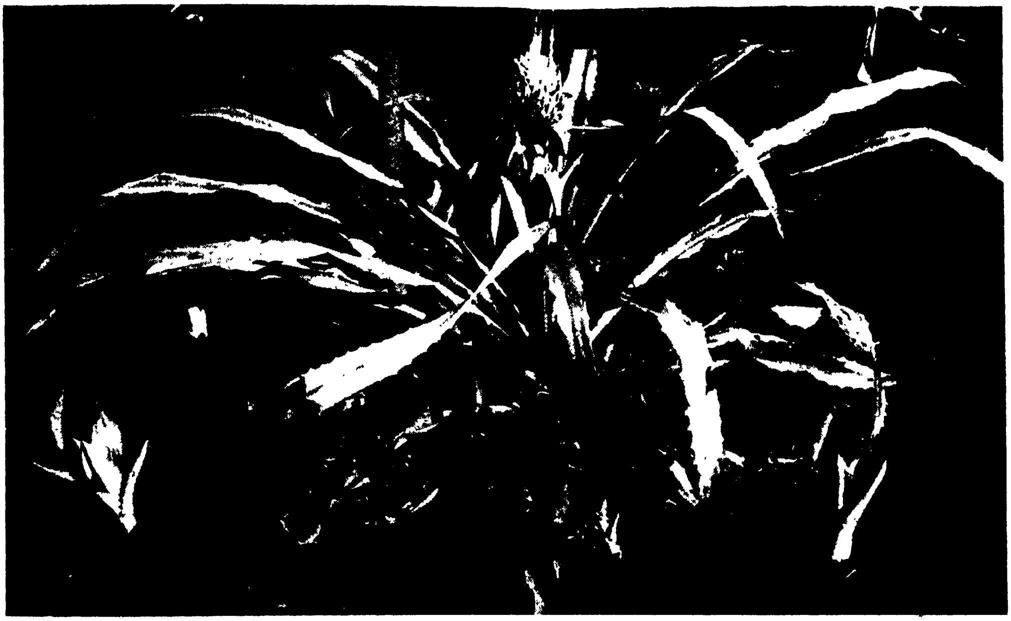

FIG. 12 (*Upper*). A young experimental field showing missing and weakened plants caused by the soil-borne heart-rot fungus, *Phytophthora cinnamomi*. Also shows the paper mulch used in several areas.

FIG. 13 (*Lower*). *Pseudananas macrodontes*, showing tall peduncle with crownless fruit and long flexible heavily spined leaves. Around the plant are four young plants arising from underground stolons.

widely between countries due to local environmental and economic conditions.

The fields intended for planting are given a most thorough preparation by repeated disc plowing and harrowing until the soil is so pulverized and mixed that it has a tilth ordinarily found only in soils prepared for gardens. This

FIG. 14. A field of pineapples in Hawaii showing two line bed type of contour planting. (*Courtesy of Hawaiian Pineapple Co.*)

thorough preparation is necessary for the method of planting used.

When an old pineapple field is to be prepared for a new planting, the first step is plowing under the old pineapple plants which represent from 50 to 100 tons of green organic matter per acre. The repeated plowings serve to chop up and to thoroughly mix these old plants with the soil. With the high temperatures and the high air humidity, this mass of organic matter rapidly decomposes in the soil.

Strips of asphalt-impregnated mulching paper, 32 to 36 inches wide, are laid on the prepared ground 20 to 24 inches apart and the edges covered with soil. At the time this paper is laid, a portion of the fertilizer may or may not be placed in the ground together with the soil fumigant known to the trade as D-D mixture (1-3 dichloropropene and 1-2 dichloropropane). There are no standard and regular amounts of fertilizer or of soil fumigant placed under the paper, and practice varies according to soil demands and plantation policy. The amount of D-D used ordinarily extends from 150 to 400 pounds per acre with the latter being more common. Magistad has listed a fertilization schedule for one area as 410 pounds nitrogen, 207 pounds P_2O_5 and 520 pounds K_2O per acre for a complete plant cycle of three years. This cannot be considered as a standard but only a sample schedule for a specific area. The amounts and kinds of fertilizers vary widely because of climatic and edaphic conditions.

Although the D-D treatment serves as a partial control of the root knot-forming nematodes which infest pineapple soils in some regions, it has additional beneficial effects on plant growth, the exact nature of which is obscure. Whatever the effects may be on various soil organisms, the development of good vigorous root systems follows proper soil fumigation in lands cropped for many years.

The application of D-D appears to suppress the activity of nitrifying organisms in the soil for eight to ten weeks during which time the plants are able to utilize ammonium nitrogen for growth from ammonium sulfate supplied to the plants.

Three to five days after soil fumigation, the plants are planted, usually in two lines on each strip of paper. This operation consists of thrusting the slips into the soil through holes punched in the paper with an iron planting tool. It is in this operation that good soil tilth is essential, for the soil should be fine enough to "flow" around the base of the slip to hold it in place and to bring soil and moisture in contact with the base of the plant to facilitate rapid root growth.

The arrangement of plants in field plantings varies widely in different countries, depending largely upon local conditions and customs. In Hawaii the plants are placed in two-line beds spaced just far enough apart to permit cultural and harvesting operations. However, in the region around Singapore, the rows of plants are placed six to eight feet apart with consequently fewer plants per acre. Here, however, the rows are widely separated in order that the laborers in cultivating and harvesting may have a better chance to avoid poisonous snakes which sometimes inhabit the fields. The statement was made by one farmer from Singapore that were the fields there planted as densely as in Hawaii, laborers would refuse to enter them.

The pineapple plant in Hawaii reaches fruiting maturity in 15 to 22 months after planting, depending upon the kind of planting material used. Suckers fruit in about 15 months, slips require about 18 to 20 months and ripe fruit from crowns is obtained in about 22 months after planting.

This first crop, or plant crop, is followed by another on the same plants approximately one year later. This is known as the "first ratoon crop", since it is produced on suckers borne by the original plant. Sometimes a second ratoon crop is obtained when the plants remain healthy. Usually about one year elapses between the last ratoon crop and a replanting of the land. Thus fields are replanted every four or five years, and these periods of crop growths are known as "crop cycles". The one year of land preparation is known as the "intercycle". Crop rotation so highly recommended for successful farming in the United States is not generally practiced in pineapple agriculture in Hawaii. This is primarily because of a shortage of available good pineapple-growing lands, secondarily because of lack of a good one- or two-year economic crop which could be used in rotation with pineapples.

The yields per unit of land area are closely correlated with the number of plants. Thus in plantings like that shown in Fig. 11, the yield should be about 32 tons of fruit per acre in the first crop with 20 to 25 in the first ratoon crop. Where the plants remain healthy additional ratoon crops may be obtained, but the yield decreases with each succeeding ratoon crop.

A large part of the pineapples produced in Hawaii is grown on land terraced and contoured to preserve both surface soil and, in areas of low rainfall, surface water. This program of soil conservation was started about 1939 with the assistance of the United States Soil Conservation Service.

Value of Paper Mulch

The question is often raised about the function of the mulch paper in pineapple fields. There are at least four fairly distinct benefits. First, and perhaps most important, is a reduction in weed growth in the area covered by the paper. The saving in weed eradication costs thus effected has been considered sufficient to justify the use of paper. Secondly, the paper increases the soil temperature in summertime from 12° to 15° F during the day, and this produces a 4° to 5° F higher night temperature. During the winter months these increases range from 5° to 8° F and 2° to 4° F day and night, respectively. Third, the mulch serves to slow down moisture evaporation from the soil surface, thus holding moisture near the soil surface in the region where most of the pineapple roots occur. Fourth, a consistently higher nitrate content has been found in the mulched soils regardless of fertilization. This indicates that the paper mulch, probably through the effects of higher temperature and moisture, brings about an acceleration of biological processes in the soil, increasing the available plant food, especially nitrates.

The mulch paper decays and disintegrates in 10 to 15 months, by which time the plants are large enough to shade the ground sufficiently to reduce weed growth and to maintain moisture near the surface of the soil.

The Need of Iron

The fact that pineapple plants in Hawaii must be sprayed at frequent intervals with a weak solution of iron, usually in the form of iron sulfate, appears to be pretty well known. There are, however, some general misconceptions regarding this phenomenon. The most prevalent one is that the soil in the Hawaiian Islands contains no iron and that this element, therefore, must be supplied. This is far from true, for the red soils of Hawaii, comprising a major portion of the land area, contain about 20 percent iron. It is this high iron content which gives it its red color. In those regions where the soil acidity is relatively high (pH 4), iron in the soil is readily available to the roots of pineapples. In these areas the feeding of plants with iron sulfate solution is not necessary for normal growth; but in those areas, mostly at lower elevations (100 to 1,000 feet), where the soil acidity

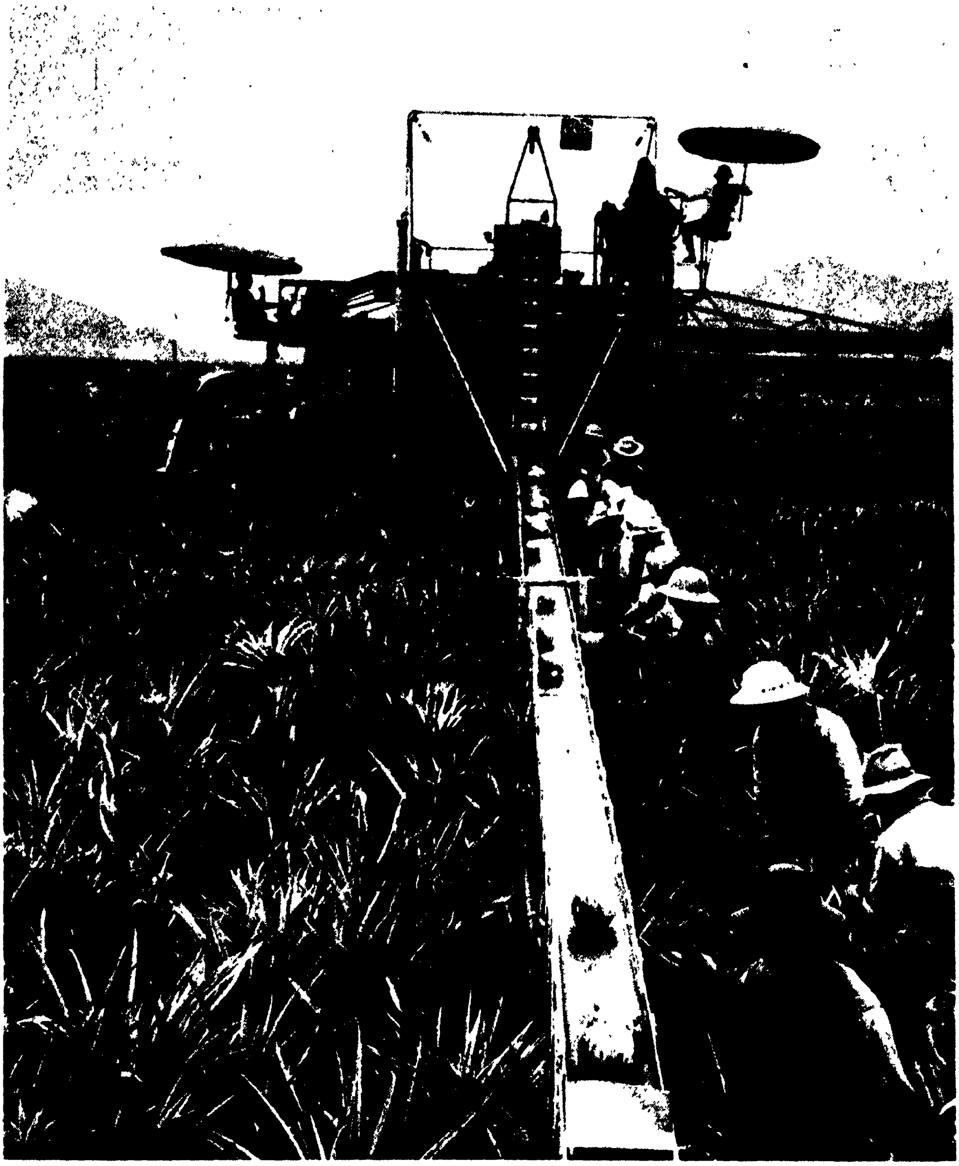

FIG. 15. Harvesting pineapples in Hawaii. Fifty-foot conveyor belt carries fruit to large box on the truck. When the truck box is filled the conveyor unit is raised up off the truck by mechanically operated legs, and the truck moves away with its load. Another truck replaces it. (*Courtesy of Hawaiian Pineapple Co.*)

is relatively low (pH 5.6–7.0), application of iron is necessary to maintain normal vigorous plant growth.

This inability to obtain iron from an iron-rich soil under certain conditions is a peculiarity of the pineapple not shared by other plants, including weeds of the pineapple fields, which grow normally under these same conditions.

Some of the soils of Hawaii also contain a relatively high percentage (5%) of manganese. In such soils the high manganese interferes to some extent with the absorption and utilization of iron, and the pineapple plants become chlorotic due to the lack of sufficient iron to produce normal amounts of chlorophyll. This also can be corrected by the application of iron sprayed on the leaves of the plant. It should be emphasized that this iron applied as a spray is taken into the plant largely through the leaves and that none or very little of it is carried up from the soil through the roots.

Under conditions of low soil acidity, iron from the soil solution is deposited and accumulated on the surface of but cannot enter the roots, according to studies by Sideris in Hawaii.

Phyto-Hormones

More than a quarter of a century ago the people of the Azores growing pineapples in glass houses discovered how to control the time of flowering and fruiting by smudging the plants with smoke in a tightly closed house. Many years later Puerto Rican growers forced pineapples into early fruiting by building smoky trash fires on the windward margins of pineapple fields. These growers were thus able to obtain ripe fruit in advance of the regular season and other growers and consequently to obtain higher prices for their crop.

In. 1932 Rodrequez, a graduate student at Cornell University, reported that pineapple plants confined in an atmosphere containing ethylene gas produced premature flowering and fruiting. In the same year Kerns in Hawaii demonstrated that two other unsaturated hybrocarbon gases, acetylene and butylene, would produce the same result when the young plants were subjected to these gases in a closed container for 24 hours.

In 1935 Kerns found that pineapple plants could also be forced into premature flowering by pouring water saturated with acetylene into the hearts of the plants. This method was promptly adapted to plantation scale application and extensively used for the control of time of fruiting on pineapple plantations in Hawaii and later in Australia.

The practical application of acetylene- and ethylene-saturated water for controlling time of fruiting in the pineapple set the stage for intensive research on phytohormones for more precise, extensive and economical control of plant growth and development. As a result of these studies the plant hormone, alpha-naphthalene-acetic acid, has largely replaced acetylene and ethylene and is now in widespread use to control time of fruiting on pineapple plantations. Other chemical substances give promise of still further control over other phases of plant growth and production.

Control of Weeds

Perhaps one of the most expensive and difficult operations in pineapple culture has been the control of weeds. This was formerly done by a combination of tractor-drawn cultivators and hand hoeing.

The inadequate labor supply during the war years forced the planters to search for other means of dealing with weeds. In this desperate situation many new processes were given trials, including the use of specially designed tractor-mounted flame throwers. As a consequence there is now a completely new procedure in the realm of weed control in pineapple fields, with the rapid acceptance and use of efficient chemical weed sprays. These include various combinations of oils, emulsifying compounds, chlorinated phenols, and water.

Similar commercial herbicide sprays are also employed. These herbicides are applied broadcast over the newly planted fields before the pineapple plants have started active leaf growth. This takes care of the early crop of weeds. After the pineapples have new leaf growth and are sensitive to the herbicide, the weed sprays are applied to the spaces between the pineapple beds by tractor-drawn spray machines which keep the herbicide close to the ground and away from the tender leaves of the growing pineapples.

The well known chemical weed sprays, 2-4-D and 2-4-5-T, while very efficient herbicides, are so extremely toxic to pineapple plants that they cannot be used in pineapple fields. Consequently other types of chemical spray mixtures have been adopted which are less harmful.

Major Diseases

As is true for most economic species, the pineapple is subject to a number of diseases and pests. Of first rank in importance because of its universal presence and influence on yield of fruit and vigor of the plant is the disease now called "mealybug wilt". Second in importance can be listed diseases caused by soil fungi which attack both root tip and stem tip growing points, causing root rot and heart rot, respectively.

Among other diseases and pests of less importance only because of limited or sporadic occurrence, several may be mentioned. Yellow spot is a virus disease which spreads through the plant and fruit from points of inoculation on the leaves or fruit, and causes complete destruction of affected plants. The virus is transmitted from wild host plants by the common onion thrips, *Thrips tabaci*, which feed occasionally on pineapple plants. This virus also causes the spotted wilt disease of tomatoes. At the present time there are no economic means of protection against this disease, and the losses are sometimes considerable, although sporadic in time and place.

The roots of the pineapple plant are susceptible to attack by several species of nematodes, among them the widely distributed root knot nematodes, *Heterodera marioni*, *Rotylenchulus reniformis* and *Tylenchus brachyurus*. The practice of soil fumigation with D-D or other chemicals has effected a measure of control for these pests so they do not have the economic importance they had before the general use of soil fumigants preceding planting of the crop.

Thecla sp., an insect of the butterfly family, is a serious pineapple fruit pest in some parts of South America. The adult female lays eggs on the flowering or growing fruit. The larvae eat their way into and spend their growth period burrowing through the fruit, causing malformed dwarfish fruits often with a gummy exudate on the surface. At one time there was a thriving pineapple industry and cannery on the island of Trinidad which was later abandoned because of the increasing percentage of fruit loss caused by this pest. The writer has observed small fields of the Pernambuco variety grown in Brazil where more than 50 percent of the fruits were infested with the larvae of *Thecla*.

At least two other fruit and plant borers are known in Central and South America, but they have caused relatively little damage to crops in the present widely dispersed manner of growing pineapples.

Several species of soil-inhabiting fungi, including *Phytophthora cinnamomi*, *P. palmivera*, *P. parasitica* and *Pythium* spp., cause severe reduction in crop yields under particular climatic conditions. *P. cinnamomi* causes rotting of both roots and stem tips during the cooler and wetter months. *P. parasitica* may occur also in somewhat warmer and dryer conditions, and attacks only the stem tip and leaf meristem areas, causing the disease called "heart rot". This rot, widespread over pineapple-growing regions, has been reported in Puerto Rico, Costa Rica, Jamaica, Cuba, Haiti, Philippines and Australia as well as in Hawaii.

Pythium, which attacks growing roots, is also widespread in the pineapple-growing areas, and causes a reduction in plant growth and vigor which is often difficult to recognize and evaluate because of variability in the degree of its effects. Although soil fumigation, which has become a regular cultural practice in Hawaii, has some adverse effect on the growth of these fungi, it does not constitute a control at the rate of application commonly used, and no adequate and economically feasible control has been found.

Mealybug wilt is a serious disease of the pineapple caused by the feeding of the pineapple mealybug, *Pseudococcus brevipes.* This disease is widespread in the pineapple-growing regions of the world, having been reported in 15 tropical countries. The time and place of its first appearance in pineapples is not known; however, the disease was recognized long before the connection with mealybugs was shown by Illingsworth in 1930 and again clearly demonstrated by Carter in Hawaii in 1931.

Diseased plants first show a loss of green color and a loss of rigidity of the leaves. This is followed by a progressive loss of green color, changing to reddish yellow, and loss of turgidity leading to complete collapse of the leaves. Along with these symptoms shown by the leaves, the roots are completely destroyed. Many plants recover slowly from this disease by first producing a few new roots and then new leaf growth from the center of the plant, but even these seldom produce fruit of commercial quality.

Before mealybugs were known to be responsible for causing wilt, the disease had spread through the plantations in Hawaii until the industry was threatened with destruction. The causal agent remained obscure for a long time after the disease had assumed serious proportions because the bugs move off the diseased plants before disease symptoms on the aerial parts become apparent. Thus visibly diseased plants seldom have mealybugs on them.

After the discovery of the role of mealybugs in the causation of wilt, attention of scientists at the Pineapple Experiment Station and the plantation men was focused on development of methods of control. Oil emulsion sprays were developed which, when applied under high pressure to the mealybug-infested plant, would produce a high measure of, although not complete, control. Large spray tanks and high pressure pumps mounted on heavy trucks force the emulsion through a 50-foot boom attached to the truck and equipped with spray nozzles at short intervals. These spray trucks travel the roads which are spaced 100 feet apart, thus spraying a 50-foot strip of plants from each road. Similar oil spray methods have been employed in other countries for the control of wilt.

Studies were also started toward developing hybrid pineapple varieties having natural resistance to the mealybug wilt. These studies demonstrated that some of the minor commercial varieties are susceptible to a less degree than the Cayenne variety used in the Hawaiian industry. Several new hybrid varieties developed by breeding these resistant varieties with the susceptible Cayenne proved to be highly resistant to the disease. The use of such genetically resistant varieties will bring about a reduction in the cost of production by elimination of some of the expense of oil spray method of wilt control.

There are a number of other minor fruit and plant diseases and pests, but none for which control methods have to be maintained.

Mechanization

Progress in the development and extension of American industry is dominated by the development of machines to replace man or animal in many of the slow routine and difficult operations. The pineapple industry is typically American in the gradual and increasing mechanizations of many of the agricultural and canning operations.

Because of the relatively small land area devoted to the growing of pineapples in comparison with the major agricultural crops of the United States, the large farm machinery manufacturers were not particularly interested in producing specialized machines required by the pineapple plantations. The mechanization of plantation operations was, therefore, carried out through the ingenuity and resourcefulness of plantation engineers and mechanics. Special machines have been developed by which the greater part of the following operations are now performed: land preparation, soil fumigation, fertilization, mulch paper-laying, weed control, hormone and iron application, disease and pest control, harvesting and fruit handling, collection and distribution of planting material.

The picking of ripe fruit is still a hand operation, but the picker now drops the picked fruit on a traveling belt in front of him which carries it to the loading truck (Fig. 15).

The planting of pineapple slips is still largely done by hand labor due to special conditions connected with pineapple planting. Most important among these are the necessity of planting the slips through a hole in the mulch paper made at the time of planting, and the variability in size of the slips, crowns and suckers used as planting material.

After the man in the field picks a ripe fruit and places it on the moving belt in front of him it is not again touched by human hands until the shell and core have been removed in the cannery. Here women wearing rubber gloves grade the fruit and place the slices in the can. From this point it is again handled mechanically.

There are still four manual operations where human judgment and skill are required. These hand operations are picking fully ripened fruit, grading the sliced fruit in the cannery according to quality standards, picking planting material from mature plants and inserting the planting material into the soil for the start of a new field. The mechanization of many operations in both field and factory has helped to maintain economic pineapple production in an industry where salaries and wages constitute a high percentage of over-all costs.

Pineapple Products

Parts of the pineapple appear on the market in a variety of forms and guises. At the top of the list the volume and value of these for the canned product are the sliced fruit in several grades, crushed pineapple, small pieces called "tid bits" and larger pieces called "chunks". Natural pineapple juice became an important pineapple product in Hawaii around 1932 and steadily increased in volume and economic importance. Now juice is being canned in several additional pineapple-producing areas as is shown in Table 4.

Frozen fresh pineapple is just emerging from the experimental stage and is

TABLE 4

ANNUAL PRODUCTION OF CANNED PINEAPPLE IN NINE COUNTRIES, EXCEPT IN THOSE COUNTRIES STARRED, FOR THE 12 YEAR PERIOD BETWEEN 1935 AND 1947. THE EFFECTS OF THE WAR ON PRODUCTION ARE SHOWN FOR THREE COUNTRIES. FIGURES DENOTE THOUSANDS OF CASES. (SOURCES OF DATA AND TYPES OF CASES ARE GIVEN AT BOTTOM OF TABLE.)

Year	*Hawaii*	*Philippines**	*Australia*	*South Africa**	*Formosa*	*Puerto Rico**	*British Malaya**	*Cuba**	*Mexico**	*Total known world pack*
1935–36[5]	10,380	149	195	67	1,189	41	2,359	[a]	[a]	14,380
1936–37	10,923	181	257	73	1,118	66	2,399	27	[a]	15,044
1937–38	12,203	590	190	62	1,200	122	3,105	167	[a]	17,639
1938–39	10,521	476	359	[a]	1,300	93	2,314	150	[a]	15,046
1939–40	10,999	992	249	[a]	1,350	93	2,875	300	[a]	16,858
1940–41	10,056	1,073	300	[a]	1,500	85	3,000[1]	300	[a]	16,258
1942[2]	10,515	495	225	80	[a]	111	0	530	15	11,971
1943[2]	11,230	0	373	81	[a]	222	0	735	56	12,697
1944[2]	11,126	0	111	85	[a]	255	0	425	95	12,097
1945[3]	10,164	0	55	79	[a]	385	0	390	110	11,183
1946[4]	9,051	0	164	42	[a]	404	12	960	214	10,847
1947[4]	10,237	0	78	120	[a]	400	50[1]	1000	500	12,385

Hawaii: Data in actual cases from Pineapple Producers Cooperative Association, report of members total pack (juice excluded).

Philippines: Shipments to the U. S. converted from pounds to cases of 45 lbs. each.

Australia: From Annual Reports of Australian Canned Foods Board in 24/30 oz. cans.

South Africa: Figures from United Kingdom imports converted to 45 lbs. per case.

Formosa: 24/2 and 3 lb. tins per case, figures from trade sources and Japanese Tinned Foods Association.

Puerto Rico: Shipments to the U. S. converted from pounds to cases of 36 lbs. each.

British Malaya: Exports converted in the basis of 48/1–1/2 pound tins per case plus estimate by Imperial Economic Committee for 1937.

Cuba: Actual cases from U. S. Bureau of Foreign and Domestic Commerce.

Mexico: Shipments to U. S. converted to 36 lbs. per case.

[1] Preliminary estimate.
[2] Data from Western Canner and Packer Yearbook 1946.
[3] " " " " " " " 1947.
[4] " " " " " " " 1948.
[5] Data for 1935 to 1941 from Western Canner and Packer Yearbook 1941.
[a] Data not available.
* Data represent the production exported to the U. S. or United Kingdom.

making its regular but limited appearance on markets of the United States. A small quantity was also recently produced in Texas from Mexican grown fruit. The quality and uniformity of this product depend very much upon the use of carefully selected field-ripened fruits, such as can be obtained only where plantation and freezing plant are closely adjacent so that the time lag between harvesting in the field and freezing is only about 24 hours.

In addition to these major fruit products there are a number of by-products of the pineapple fruit important economically but relatively unknown outside the pineapple-growing areas.

Pineapple bran, for instance, is made from the outside shells of the fruits. After extracting most of the juice the shells are chopped into fine pieces and passed through steam heated evaporators which remove much of the remaining moisture and also serve as sterilizers to prevent molding. The chopped shells are then placed in bags and sold as dairy and other farm stock feed. The largest quantity, however, is used in dairies.

This bran is high in carbohydrates, having about 54% starch and sugars, along with about 3.5% protein, 10% water and 18% fiber. It also contains about five times as much vitamin A as the cereal grains, and vitamin B is present to about the same amount as it is in whole wheat, according to nutrition studies carried on at the University of Hawaii.

Originally some of this bran was shipped to California, but now all of it is used in Hawaii. Some of the can-

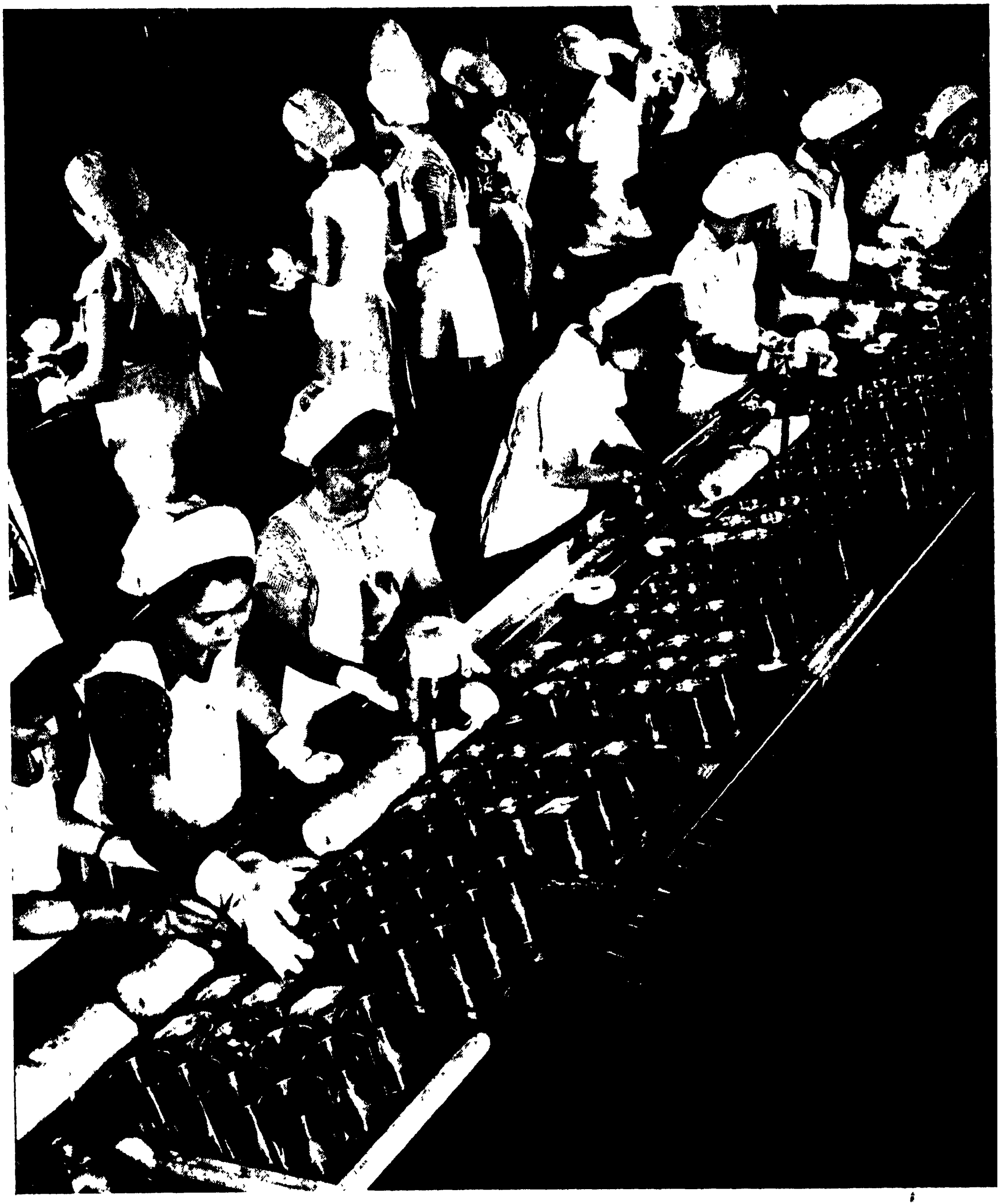

FIG. 16. Placing sliced pineapple in cans, one of the few hand operations remaining in a highly mechanized industry. (*Courtesy of Hawaiian Pineapple Co.*)

neries sell the pineapple pulp from which most of the juice has been expressed, but without drying, directly to dairies and cattle ranches where it is either used at once or stored and used as silage later. One large dairy only about ten miles from Honolulu mixes fresh pineapple pulp in alternate layers with a large coarse sorghum-like grass (*Pennisetum purpureum*) in a horizontal silo dug into the ground.

Sugar syrup is also recovered from pineapple juice either by concentration or by the process of ion exchange, and is used in the canning of pineapple fruit products. Other by-products recovered from the juice are commercial grade (95%) alcohol and citric acid. Formerly carbon dioxide gas was also produced.

A small quantity of pineapple is also used in Hawaii and in several other countries for the production of candied fruit, jams, *etc.*

A very fine quality of cloth similar to the best grade of linen is made from pineapple leaf fibers in the Philippines. This is not a new product, for a missionary in the Philippines reported in 1591 that piña cloth was produced by the natives from the leaves of the pineapple plant.

Bromelin, a protein-digesting enzyme, has been produced in small quantities from pineapple juice, but because of the high cost of extraction it cannot be produced economically with the present high cost of pineapple production.

Although the American Indians were reported to have used pineapples for making wine long before Europeans came to the New World, very little of the fruit is now used for this purpose. Small quantities of brandy and liqueurs are, however, produced in the Azores, Cuba and Brazil. Some of the United States troops stationed in Hawaii during the recent war, often adjacent to or in pineapple fields, learned through their own ingenuity some of the methods probably used by the Indians of ancient America for producing alcoholic beverages from ripe pineapples.

World Production of Canned Pineapple

We have shown that pineapples became established rapidly in tropical countries around the world after their discovery in America. Their cultivation, however, remained on a small scale, supplying only local markets, until the beginning of the present century when the canning of pineapples was initiated in Hawaii. This canning industry grew steadily until by 1936 it was producing the major portion of the world supply. A smaller amount was produced in a number of tropical countries but primarily in the eight additional countries listed in Table 4. This table is intended to show the major countries where a considerable portion of the annual crop is canned. However, in listing pineapple-growing areas we cannot omit Brazil, the original home of the pineapple. Relatively little canning has so far been done in that country, but a considerable acreage is devoted there to growing pineapples, either as a sole crop or interplanted with other crops. Usually the fields are small, but in some parts of the State of São Paulo large fields are planted. A majority of the Brazilian pineapples is exported to Argentina and Uruguay as fresh fruit, and the rest used locally in Brazil.

Because of the diversity of planting methods, sole crop or companion crop, and the number of plants per unit area, no attempt is here made to compare land areas employed in growing pineapples. Table 4, therefore, uses the amount of canned fruit produced as a means of indicating the relative production in different countries.

The United States has always absorbed most of the pineapple canned in Hawaii, and there has been very little diverted to foreign markets. Before the war a small amount of canned pineapple from foreign countries, primarily the Philippines, Formosa and the West Indies, was also marketed in the United States. Australia, British Malaya and South Africa exported canned pineapple to countries in the British Commonwealth.

Mexico, like Brazil, has produced pineapples for a long time, most of which were used locally, shipped as fresh fruit or preserved in brine in barrels. Within the last few years more attention has been given to canning of the fruit. This change is largely due to the difficulties in transporting the fresh fruit to the larger city markets rapidly enough to prevent great losses due to spoilage.

The war abruptly stopped pineapple production in the Philippines and British Malaya and prevented export of pineapple from Formosa, except to Japan. During the war years the plantations in Malaya and the Philippines reverted to jungle, and the canning factories were stripped of their machinery by the Japanese. In some places the buildings were removed for use elsewhere by the invaders.

The production data in Table 4 include pre-war years in order to show the normal contribution of these war damaged countries to the total world production of canned pineapple during that period.

The pineapple industry in these countries, particularly the Philippines and British Malaya, is now being re-built and can be expected again to make a normal contribution to the world supply. Increased production is also reported for some of the tropical countries.

The United States government purchased more than 60 percent of the Hawaiian pineapple pack during the war years, 1942–1945. This diversion of a large part of the Hawaiian production from the normal civilian markets created a scarcity throughout the United States which has not been completely relieved up to the present time, but the degree of shortage is being gradually reduced. This lag in supplying the market demands was, in part at least, due to the complete exhaustion of the stock in dealers' warehouses and shelves throughout the country during that five-year period of short supply.

Utilization Abstract

Flax. In 1937 seed flax fibre for the paper industry was produced for the first time in the United States, 927,000 acres being harvested that year with a yield of a little more than seven million bushels of seed. In 1948 about 4¾ million acres were harvested, producing 52½ million bushels of seed. During the intervening period over two million tons of seed flax straw were bought for the paper industry from farmers for about $5 million, about 10% of it being California straw, about 90% from the general Minnesota area.

"The cigarette and fine paper industry has used during this period about 445,939 tons of seed flax fibre and accumulated, as of the date, an inventory of about 52,000 tons. Fibre consumption appears to have leveled off at about 60,000 tons per year. In addition to fibre inventory, a large inventory of undecorticated flax straw is carried on hand as a safety factor in case of poor crops".

"The paper industry uses the fibre separated from the straw, which is, roughly, 27% of the weight of the straw processed. . . . The approximately 73% of residue (shives) is partially utilized at present as fuel, wall board stock, feed and bedding".

This utilization of flax straw, formerly a great farm waste, and the research in agronomy, chemistry and plant breeding necessary for its development, have been the work of the Ecusta Paper Corporation which began making cigarette paper from flax at Pisgah Forest, N. C., in 1941. Flax fibre was first successfully processed into cigarette paper in 1937. (L. F. Dixon, *Chemurgic Digest 8 (8): 9. 1949*).

Mycological Production of Citric Acid—*the Submerged Culture Method*

Industrial production of citric acid through the fermentation processes of fungi is being carried on by three companies in the United States. Application of recently developed submerged culture methods have produced yields as great as those obtained by the longer established surface culture technique.

D. PERLMAN[1]

Introduction

Within the past ten years the submerged culture method of growing fungi has been successfully applied to many fermentations where formerly only the surface culture method was used. A general discussion of this development has recently appeared in this journal (19), wherein it is stated that in the United States at the time of writing that article, only one company was believed to be engaged in the manufacture of citric acid by fermentation, production amounting to approximately 35,000,000 pounds in 1948 by this process. The submerged culture method, first described in detail by Kluyver and Perquin (34, 49), consists of growing the mold in a vessel which is agitated and aerated so that the mycelium forms throughout the culture liquid, resembling a suspension of paper pulp. It has been applied to many mold fermentations, including those producing citric acid, fumaric acid, penicillin, gluconic acid, lactic acid, oxalic acid, ethanol, kojic acid and itaconic acid. Many of the problems associated with growing these fungi in surface culture have been noted when the organisms were grown in submerged culture, including such matters as cultural variation, nutrition and effect of aeration on metabolism of the organism. However, the relative importance of these problems is often changed when the organism is grown in submerged culture as compared with the problems encountered when surface culture is used, and study and reinvestigation of these problems are often necessary when this change is made.

While the surface culture method for growing mold cultures has been used for more than half a century, it is rather uneconomical and inefficient when compared with the submerged culture method. Large scale operation of the surface culture method entails considerable labor per unit of medium handled, since the pans or large bottles usually used have to be inoculated, harvested, inspected and cleaned by manual labor. In the submerged culture method large tanks are used, often with capacities of over 15,000 gallons, and the labor per unit of medium is considerably less than in the surface culture method. Also, the amount of space required for the processing of a given amount of medium is considerably less in the submerged culture method. Such matters as temperature control, sterility control and preparation of media are also attended to more efficiently in the submerged culture method.

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For practical purposes the submerged culture method offers economic advantages over the surface culture method. However, since many of the mold fermentations have been first studied in surface culture, usually because in the laboratory surface culture methods are more easily used and less expensive with regard to equipment, adaptation of the techniques learned in investigations of these fermentations to submerged culture is usually somewhat involved. The mycological production of citric acid is one of the mold fermentations which has been studied in surface culture for many years, and only rather recently has it been studied in submerged culture. This fermentation product is of considerable economic importance, and at present the mycological product has succeeded the citrus fruit by-product on most markets (53, 68, 74). Production has been estimated at 35,000,000 pounds in 1948, an increase in ten years of nearly 20,000,000 pounds. While large scale production of citric acid by the mycological process in surface culture on a commercial basis did not start until 1923 (50, 74), considerable advances have been made in the intervening period, and the production has increased while the cost of the product has decreased. At first a medium containing purified sucrose as carbohydrate source was evidently used, but more recently a process utilizing a medium containing molasses (beet or cane) has been perfected, and thus the cost of the substrate has been reduced. The bulk of the citric acid manufactured by this process is made by the firm of Chas. Pfizer & Co., New York, and since 1935 very little citric acid has been imported into the United States from Europe.

The problems encountered in the surface culture method have been recently reviewed (19, 68) and will not be mentioned in the following discussion except as they bear on problems encountered in the submerged culture process. All of the reports on the submerged culture method refer to laboratory experiments carried out in flasks or other laboratory size vessels. These vessels are aerated by shaking or passing gas mixtures through the liquid, and often agitation is simultaneously applied. Use of large fermentation units has not been reported, but it seems probable that such units as are used in the mycological production of antibiotics could be adapted for mycological production of citric acid, although at one time this prospect did not appear to be reasonable (74).

Several decades have passed since Amelung (1) reported the production of citric acid by *Aspergillus japonicus* when grown in submerged culture. Perquin (49) made a rather detailed study of many of the problems involved in the production of citric acid by this method, and many of the subsequent studies (31, 32, 63, 64) have been elaborations and extentions of this primary work. Within the past few years several investigations have given rather contradictory results, and recent papers (47, 55–57) indicate that several matters which were thought to be of rather minor significance are of apparently major importance. It is probable that all of the conditions affecting the mycological production of citric acid by the submerged culture method have not been recognized, but recent high production yields indicate that perhaps the major problems have been solved.

Selection and Maintenance of Cultures

Citric acid has been reported as a metabolic product of many molds, usually grown in surface culture. Among them have been *Aspergillus niger* (*Sterigmatocystis niger*) (68, 73), *Botrytis cinerea* (12), *A. clavatus* (68), *A. wentii* (31, 69), *Penicillium luteum* (14, 15), *P. citrinum* (14, 15), *P. johannoli* (14, 15), *P. citrogenum* (14, 30) and *Mucor piriformis* (68). Not all of these organisms have been tested in submerged culture; among those so studied and found to produce citric acid are *A. niger* (49, 47, 55, 63), *A. wentii* (31, 70), *P. chrysogenum* (49), *Sclerotium delphinii* (43) and *Polyporus anceps* (48). It is probable that all organisms producing citric acid in surface culture will produce it in submerged culture under suitable conditions. As will be seen from the following discussion, certain cultures of a given species, and certain genera, appear to be more sensitive to certain fermentation conditions than other cultures and genera, and thus selection of cultures for study and evaluation of results obtained should not be based entirely on the performance found in surface culture.

In a study of 72 *A. niger* cultures obtained from different culture collections and presumably of different origin, it appeared that all the cultures produced an appreciable quantity of citric acid when grown in submerged culture on synthetic media (sucrose and inorganic salts) or on molasses media (47). Only a few of this group, however, produced large amounts of acid under the fermentation conditions used, *e.g.*, more than 50 grams of acid from the fermentation of 100 grams of sucrose, and it seemed quite obvious that these cultures differed physiologically from the others. A similar survey (56) of a smaller group on a synthetic medium obtained the same general result. It is probable that a similar situation will be found in investigations of citric acid production by other species and genera.

Complicating this choice of culture are the reports on culture variation (4, 6, 18, 33, 22). This variation was first noted in studying the citric acid production by *A. niger* in surface culture (18, 46). Subcultures obtained by isolation of single spores from a high or low producer have shown considerable variation in their ability to produce citric acid. These isolates do not differ from the parent culture morphologically, and seem to grow as well as the parent culture on all media, but often produce far less or far more citric acid than the parent culture. This evidence might be interpreted to indicate that these cultures of *A. niger* really consist of mixed populations. It seems probable that these are the results of natural variation, since they apparently occur with approximately the same frequency in cultures derived from single spore isolations as in cultures transferred by mass inoculation procedures. Preliminary studies indicate that the same general behavior is noted with the cultures found suitable for use in submerged culture process (47).

Once the desired culture has been selected, care must be taken to "stabilize" it so that a constant inoculum may be obtained. This has been done in other microbiological processes by drying the spores on soil, or by lyophilizing them in serum or milk (3). In studying the production of citric acid in surface culture it was noted (18) that the storage conditions of the stock cultures dried on soil was very important. Best results were obtained when the stock cultures were stored at ice-box temperatures, and very poor results were obtained when they were stored at 37° C. Similar observations (47) were made in connection with the storage of soil stocks of cultures used in the submerged culture process.

The observed cultural variation mentioned above has suggested the possibility that induced variants, sometimes called "mutants", of these cultures might be selected by various means and would be found to be better adapted than the parent cultures to the production of citric acid under certain fermentation conditions. The effect of various chemical agents in inducing variations in a number of the aspergilli have been studied (61, 67), and several reports (21) have appeared in the literature indicating that such agents as ultra-violet light, carcinogenic hydrocarbons and x-rays will cause morphological and presumably physiological changes in cultures exposed to these forces. Unfortunately these reports are of a preliminary nature, and consideration of the possibilities of this approach awaits presentation of a detailed study.

The agar medium used to grow the spores in preparation for inoculation of culture flasks is of considerable importance when cultures of *A. niger* are used. Shu and Johnson (55), in studying acid production by one strain, have shown that the presence of traces (0.1 p.p.m.) of manganese salts in the medium used in this stage results in considerable reduction in citric acid yields, presumably due to carry over of maganese to the fermentation stage from the inoculum. They found that this effect may be partially reversed by including zinc salts. Observations with other strains of this organism (47) have confirmed this report that inclusion of manganese salts in the agar media used for growing the spores is undesirable, and also that this effect may be minimized by inclusion of iron salts in the media. However, not all cultures of *A. niger* are so affected, and it is probable that this effect will not be found in other genera. Nevertheless, it is of interest that such a minor operation as the preparation of inoculum medium has such an effect on the results of the fermentation. Solid media, such as oat meal and wheat grains, has been used with some success for the preparation of spores (49).

While several types of inoculum may be used to inoculate mold fermentations in laboratory vessels of larger equipment, the results obtained when vegetative growth is used appear to be more reproducible than when a spore suspension is employed. Use of a spore suspension obtained by scraping the spores from a culture grown on agar media or on starchy materials, *e.g.*, wheat grain, oat meal or rye grain, is adapted for laboratory experiments and has often been used. However, the effects mentioned in the previous section regarding the influence of the medium used for production of the spores make the use of more inoculum a more important factor in determining the ultimate success of the fermentation than is usually appreciated, and perhaps in time this method will be discarded in favor of vegetative growth.

A vegetative inoculum phase is desirable for large scale operation, since it reduces the time required to complete the fermentation cycle. This vegetative inoculum may be grown on media similar to the medium used in the larger fermentation unit, or may be grown on entirely different media. Opinions favoring both types of media have been noted in the literature. Three investigators (32, 49, 63) report that the inoculum should be grown on a complete medium and then transfered to a deficient medium. This practice is feasible on a small scale but certainly has limited application for large scale operations, especially if the fermentation is to be kept bacteriologically uncontaminated. Shu and Johnson (56) have used a spore suspension in their laboratory experiments and have observed that no advantage was gained by the use of two media. They have suggested that the alternate practice arises from the use of an unbalanced fermentation medium.

The size of inoculum used in fermentation grown under submerged culture conditions may vary from three to 40 per cent of the final volume of the fermentation. When the method described by Szucs (63) and Karow (31) is used, the inoculum could be considered to consist of 100 per cent of the fermentation volume. Generally in large scale submerged culture work, several vegetative stages are used, starting with small units, *e.g.*, Erlenmeyer flasks, and building up to larger units, *e.g.*, 500 gallon tanks, in several stages.

Selection of Media

Synthetic Media. Many of the preliminary experiments have been confined to the study of citric acid production on media in which all the constituents were known, usually called "synthetic media", for it has been hoped that under these controlled nutritional conditions it would be possible to ascertain and understand the factors affecting citric acid production. While this reasoning is thought to be sound, it may result in making the situation too simple or too complex. For example, citric acid production by certain strains of *A. niger* is markedly affected by the presence of as little as 0.1 p.p.m. of iron in a synthetic medium. Thus use of this culture would be limited to media which contain less than this amount of iron, and of course this would in turn mean that certain raw materials could not be used, *e.g.*, molasses, and that certain equipment made of iron or steel could not be used. An analogous situation is found in the toxic effect of iron on the production of riboflavin by bacteria (2) and yeasts (65, 66). In some cases fermenters were constructed of aluminum to circumvent this difficulty. It would seem from this observation that the use of molasses as a carbohydrate source could not be considered, since it is heavily contaminated with inorganic constituents. It is possible, however, that the metallic ions present might counteract each other, as has been noticed in other fermentations, or that addition of certain salts would serve to counteract the undesirable effects. When these considerations are kept in mind, it will be seen that the use of synthetic media has a definite place in studies on citric acid production. It appears almost necesary to use synthetic media for studies on the mechanism of mycological production of citric acid.

As mentioned above, by definition a synthetic medium is one in which all of the constituents are defined quantitatively. Since most of the fungi used in the mycological production of this acid are sensitive to metallic ions, analyses of the media are necessary. Too few investigators have troubled to determine the metallic ion content of their basal medium when studying the effect of metallic ions on acid production, and did not indicate that the basal medium, usually containing carbohydrate, inorganic salts and water, was contaminated with biologically significant quantities of metallic ions. These entered as impurities in the constituents (45, 44, 60). It is usually assumed that chemically pure constituents are also biologically pure; reflection will remind one that C.P. usually indicates that a substance is only 99.90% pure and that as little as 0.01% of a metallic ion impurity will influence biological growth. Since the presence of as little as 0.1 p.p.m. of iron, copper, aluminum, manganese, zinc and other metallic ions may markedly affect citric acid production (45) when these elements are added singly, the cumulative effect may be expected to be tremendous. Thus it is almost always necessary to purify the constituents of the media to remove the metallic ions.

Several methods have been suggested to accomplish such removal from carbohydrates and non-ionic fractions of the media (60). Shu and Johnson (56) have used an aluminum hydroxide adsorption procedure with success. A calcium carbonate adsorption method has also been used (60). Metallic ion complexes were formed with 8-hydroxyquinoline, and then the complex was removed from the medium by extraction with extraction with chloroform (71). Other chelating agents may be substituted for 8-hydroxyquinoline, and some may be left in the medium (27, 28, 53*a*), since they do not interfer with the progress of the fermentation.

A rather non-specific method is the use of ion-exchange resins (44, 45). This results in removing quantities of all of the metallic ions present, and can be applied only to the non-ionic fraction of the media. The method has been applied with success to various media (26, 31, 45, 52, 66, 39, 75).

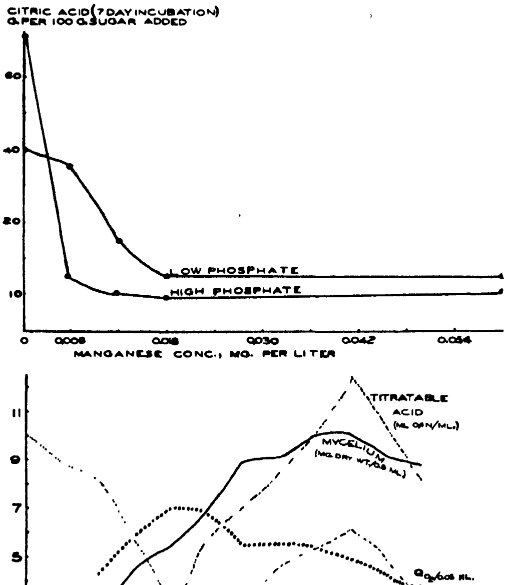
Purification of the inorganic constituents of the medium is rather difficult and a tedious process. Recrystallization of the salts is usually only partly satisfactory, and it is often easier to prepare the salts from purified raw materials (Hutner, personal communication).

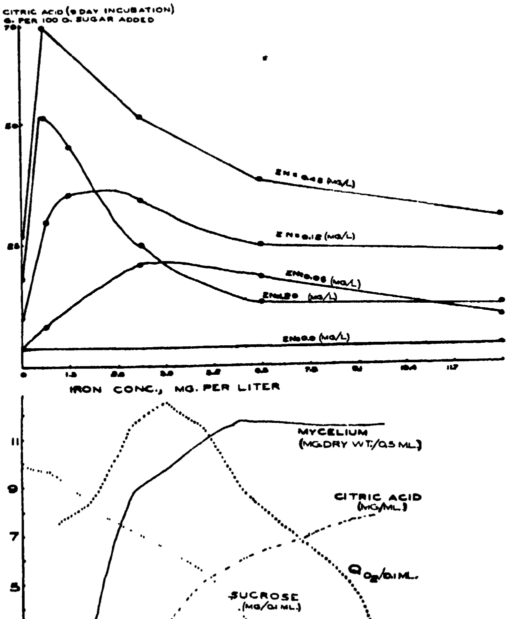
Selection of carbohydrate materials for fermentation studies in the past has usually been confined to glucose or sucrose. Citric acid production on media containing other sugars, including fructose, as well as inulin, starch and dextrin, has been reported (69, 47). As most of the fungi which are used produce amylases, the use of polymers of simple sugars is to be expected. It appears that these substrates must be purified before use, for apparently it is the inorganic impurities which must be removed (47).

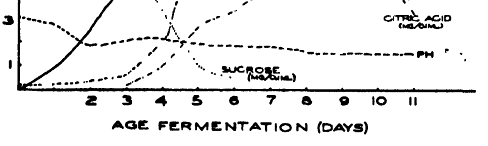
The optimum concentration of carbohydrate in synthetic media used in laboratory studies seems to fall between 100 and 150 grams per liter. If higher concentrations are used, the fermentations must extend over a long period to convert the maximum amount of carbohydrate to acid, and the efficiency of the process is often diminished. Also, many of the cultures apparently do not tolerate high concentrations of acid and will stop metabolizing the substrate when such conditions exist. If lower concentrations are utilized, it is apparent that the quantity of substrate used in the formation of mycelium is necessary, *e.g.*, if a medium containing 50 grams per liter of sucrose is used, as much as 35 grams per liter are used for growth and energy, while if the medium contains 100 grams per liter, only 45 grams are used for mycelium formation and energy. When sufficient purification has been achieved, yields on media containing glucose, fructose or sucrose have ranged from 50 to 75 grams of citric acid, calculated as anhydrous acid, for every 100 grams of carbohydrate fermented (57). It is probable that yields on synthetic media containing other carbohydrates will approach these figures.

Several organic and inorganic nitrogen sources have been used in synthetic media including ammonia salts, nitrates and such potential ammonia sources as urea and amino acids. A comparison (56, 16) of these sources has not indicated that any one is better than the others. It is possible that the advantages sometimes noted (31) are evidences of the purity of the compounds used. Most of these cultures used in laboratory experiments produce significant quantities of proteinase, and it is possible that polypeptides might be used as efficiently as inorganic nitrogen sources. While detailed reports are not available, it is probable that a great excess in the medium of biologically available nitrogen is to be avoided (56, 16).

Many of the studies on the mycological production of citric acid have indicated that the balance of inorganic nutrients, mainly traces of minor elements, is very important. While all investigators find that media should contain phosphate, magnesium and potassium salts as well as small quantities of iron, manganese and zinc salts, it is the balance of these salts that appears to be important. Evidently this is the object of the two-stage process, used by Szucs (63, 64) and Karow (31), in which the mycelium is grown on a medium containing phosphate and then transferred to one without phosphate, where acid production proceeds. These investigators indicate that with the cultures used (*A. wentii* and *A. niger*), good yields of citric acid are dependent on the absence of biologically available phosphate in the fermentation phase of the process. Shu and Johnson (56), working with another culture of *A. niger*, have shown that it is not the phosphate alone which is important but rather the balance of manganese, zinc and phosphate. This relationship is illustrated by the data in Figure 1, where acid production on a high phosphate medium in the presence of a trace of manganese was lower than that obtained on a low phosphate medium. (This observation has been made independently by Georgi and associates, personal communication). Shu and Johnson also noted that if the two stage process is







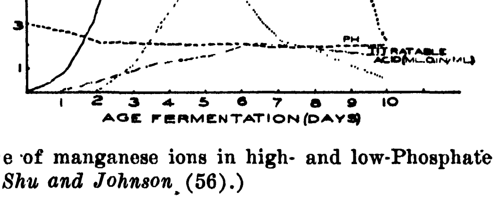


FIG. 1 (*Upper left*). Effect of the presence of manganese ions in high- and low-Phosphate media on citric acid production. (*Courtesy of Shu and Johnson* (56).)

FIG. 2 (*Upper right*). Effect of concentration of iron and zinc ions on citric acid production. (*Courtesy of Shu and Johnson* (56).)

FIG. 3 (*Lower left*). Chemical changes occurring during fermentation of sucrose-salts medium by high-yielding culture of *Aspergillus niger*. (Abstracted from (47).)

FIG. 4 (*Lower right*). Chemical changes occurring during fermentation of sucrose-salts medium by low-yielding culture of *Aspergillus niger*. (Abstracted from (47).)

used, phosphate must be added if the mycelium (grown on a "complete" medium, *e.g.*, high phosphate) is carefully washed free of adhering phosphate. It seems probable that standardization of this two-stage process would be difficult, since residual phosphate would be held by the mycelium.

The importance of iron, zinc, manganese and other of the "minor" elements has been stressed (47, 49). It is probable that the similar interrelationships mentioned by Shu and Johnson (56), illustrated for iron and zinc in Figure 2, will be found for these elements. The role of iron appears to be concerned with utilization of the citric acid formed as well as with growth of the organism (20, 47). If periodic additions of iron are made to high-yielding fermentations, the rate of citric acid utilization is markedly increased, and by careful adjustment it is possible to prevent accumulation of any acid. It is probable that a similar role will be found for the other elements used in most media. These studies with iron (47) have been made with several strains of *A. niger* and indicate that, while all strains are sensitive to the presence of iron and while all strains will metabolize citric acid, the degree of sensitivity to iron varies markedly and is perhaps related to the ability of the culture to use iron citrate rather than "free" iron. It is probable that other fungi will not be so sensitive as *A. niger* to the presence of iron, since they are not inhibited by cyanide (30). This perhaps indicates why addition of calcium is necessary if strains of *Penicillium* are used (76) (experiments done in surface culture, but undoubtedly bear on the submerged process), and suggest that the *Penicillium* cultures cannot utilize calcium citrate, and thus the citric acid accumulates.

Calcium salts have often been added to media used for citric acid production, in both surface and submerged culture (49, 76), with varying effects on acid production. Hutner (27, 28) has suggested that calcium salts act as a negating agent, neutralizing the undesired effects of other metallic ions, as shown in his experiments with bacteria. Addition of calcium serves to buffer the medium, and when it is added to growing cultures of *A. wentii* and *A. niger* (31, 49), oxalic acid accumulates, and less citric acid is found. The accumulation of oxalic acid seems to be separated, however, from the accumulation of the citric acid, and may occur because calcium oxalate is relatively insoluble and biologically unavailable. On the other hand certain cultures are markedly inhibited by the citric acid they produce, and citrate accumulates in significant quantities only in the presence of a neutralizing agent (43, 76).

Studies on the effect of the addition of many metallic ions on the production of citric acid in surface culture have not indicated that any one is essential for citrate production. Recent studies in submerged culture under rather controlled conditions (56, 47) have not shed any light on this aspect, even though highly purified media were used. As might be expected inclusion of some of these had no appreciable effect on citrate yields, while others resulted in a significant reduction of citrate yields. Sjolander (58) has added strips of a number of alloys to shaken flasks fermentations and noted that only the addition of strips of aluminum alloy did not cause reduction in acid production. The reduced yields of acid noted when the other alloys were present was undoubtedly due to the metallic ions added to the medium by the solution of the alloys.

Addition of vitamins and organic growth factors to *A. niger* fermentations in surface culture has not resulted in increased acid production (44), and it is expected that a similar situation will be noted with the submerged culture process (56). However, if other organisms are used for the production of citric acid, including *Polyporus* sp. (48) and *Botrytis cinerea* (17), addition of thiamin to a synthetic medium is necessary in order to obtain growth. While these organisms have been found to produce very small amounts of citric acid when grown in submerged culture, it is possible that production might be increased under favorable conditions.

Essentially the same process used for the recovery of citric acid from surface culture fermentations (9, 10) may be employed for the recovery of acid from submerged fermentations. The mycelium is collected by filtration, calcium oxide is added to the filtrate, and the mixture heated. The precipitated calcium citrate may be purified by recrystallization, and the citric acid regenerated from the calcium salt with sulfuric acid. The commercial product is usually citric acid monohydrate. The collected mycelium contains significant quantities of B-complex vitamins and amino acids, and has value as a feed supplement similar to other mycelia (62).

Natural Media. The above discussion has been concerned with media in which all of the constituents are known and thus individually of reasonable purity. Economically this has disadvantages, for purification of the ingredients is expensive, and less pure materials are of course usually less expensive. While the surface culture process when started commercially as a medium contained purified sucrose, more recently beet molasses and cane molasses have been used (68). These substrates are considerably less expensive than the purified sucrose, and under present conditions a commercial process must use them to meet competition.

Citric acid production has been studied on media containing inexpensive and readily available carbohydrates, including cane molasses, beet molasses, maltose syrups, starch products, cellulose hydrolyzates and similar materials. Several grades of each of these classes have been studied in the surface culture process (69, 42), and some of them have received attention in the submerged culture process (31, 47, 58). These substrates are of variable composition, and a somewhat flexible fermentation process must be designed if they are to be used. The available data indicate that under suitable conditions fairly high yields of citric acid may be obtained on media containing molasses and similar crude carbohydrates.

Since molasses and starchy materials contain large quantities of materials of unknown composition, purification of these materials is often attempted to reduce the amounts of undesirable substances and make the substrate usable. The data available dealing mainly with citric acid production by aspergilli (31, 25, 46, 58, 33) in surface and submerged culture indicate that removal of certain of the inorganic constituents of the molasses results in increased acid production. Analyses of various samples of molasses (44, 46, 54, 25) have shown that certain products contain considerable ash, sometimes as high as 20 per cent of the weight of molasses. Reduction of this inorganic fraction by treatment with ionic-exchange materials (7, 8, 26, 39, 72), charcoal (31, 38), chemicals (38, 25, 29) and other materials (28, 40) has resulted in a product which may be used for the production of citric acid. Beet molasses contains significant quantities of nitrogen and phosphates, while cane molasses is low in these ingredients (44), and nitrogen-containing compounds and phosphates are usually added to media prepared with cane molasses, while such additions are not necessary when beet molasses is used. The ionic exchange treatments (46) which are well adapted to remove the inorganic constituents from molasses do not remove all the nitrogenous compounds. Purification of molasses by these procedures is likely to be an expensive process, and the cost may determine in part the feasibility of using these substances as substrates. Crude starch has a low ash content, much lower than most types of molasses, and purification of this substance may be less expensive than purification of molasses. Thus while starch costs more initially, it may have advantages over molasses whose initial cost is low but whose purification cost may be high.

Few data are available on fermentations which have used these crude carbohydrate sources as substrates for the submerged culture process. It appears that after suitable treatment rather high yields may be obtained (47, 32, 58). The same problems that are found with the use of synthetic media are encountered with this type of media. These include culture selection, incubation temperature, aeration methods and recovery methods. When crude substrates are used there are perhaps more difficulties encountered. Certainly recovery of the citric acid is more difficult, since the product is likely to be colored from adsorbed materials, and frequently recrystallization is necessary. Selection of cultures is often more difficult for a comparable process utilizing synthetic media, for the molasses often appears to contain substances inhibitory to citric acid production though not to growth. Cultures which are satisfactory for the synthetic media are often not useful for molasses media, but fortunately cultures which do well on molasses media also do well on synthetic media (47, 32).

Fermentation Conditions

Aeration. The foregoing discussion has been concerned mainly with the effect of constituents of the medium on citric acid production under given fermentation conditions. Several reports are available illustrating the effect of changing the fermentation conditions on acid production. One of these factors which has received study in several laboratories is that of different aeration methods on acid production (32, 47, 56). Nearly all of the laboratory studies have used shaken Erlenmeyer flasks as fermentation vessels (32, 47, 56, 58, 49) and have conducted a few studies in which the fermentations were grown in flasks aerated by passing gaseous mixtures through fritted glass plates or porous stones, indicating that this method may be also used (31, 63). Various gas mixtures have been passed through fermentations in these latter vessels. Szucs (63, 64) and Karow and Waksman (32) have found that use of oxygen resulted in best yields, while others have obtained good yields when air was supplied (47, 53*a*, 56). It is apparent that under either of these conditions the fungus does not use more than 5% of the oxygen passed through the medium, as ascertained by measurement of the carbon dioxide content of the exhaust gas, and it is presumed that aeration accomplishes more than to provide a source of available oxygen. Study of the data does not indicate why oxygen is desirable when a low phosphate medium is used (31, 63), and repetition of these experiments in another laboratory (56) has indicated that air may be used with other cultures of *A. niger* when grown on these media. Szucs (64) has reported that addition of milk colloids has resulted in increased citric acid production, which he attributes to the effect of the colloidal particles on the dispersion of the air.

The methods by which fermentation vessels are agitated has a direct effect on aeration efficiency in submerged culture fermentations (11, 59). Agitation and mixing are often increased by use of paddles, baffles and pumps for recycling a portion of the vessels' contents. As laboratory studies have been mainly confined to small scale fermentations, no data are available concerning the difficulties in adapting the fermentations to large scale operations, but similar problems are expected to arise as were noted in the penicillin process (11, 59).

Temperature. The effect of the temperature of incubation during the fermentation period on citric acid production has received some study in both the surface culture process (41, 35, 44) and the submerged process (47). Nearly all of the organisms studied will grow well when incubated in the range of 15–40° C. However, growth is not necessarily to be associated with citric acid production, and, as noted by Perlman (47), nearly all strains of *A. niger* tested produced rather high yields of citric acid when incubated at 24–30° C., but practically no acid when incubated at 37° C. The quantity of mycelium found at the higher temeprature was as great as that at the lower temperature. The data are too fragmentary to allow much speculation regarding possible reasons for this situation, but do indicate that metabolic rates are usually higher at the higher temperatures, and that citrate is metabolized at a faster rate at the higher temperature. Certain strains of *A. niger* appear to produce more citrate than others at the higher temperature, but this may be the result of the observation that these cultures do not utilize the citrate formed as rapidly as do the so-called "poor" producers.

Culture Techniques. Mention has been made of the two-stage process used by Szucs (63) and Karow and Waksman (32, 70). This process is similar in plan to the "reuse of mycelium" practice used successfully in surface culture fermentations (13), where the fermented medium is removed from underneath the mycelium and replaced with fresh medium. While in surface culture practice it is comparatively simple to remove and replace the medium without disturbing the mycelium, this operation becomes rather complicated in the submerged culture process. The mycelium in this latter process is rather shapeless and without rigidity, and filtration results in "packing" of the mycelium and makes washing of the collected material rather difficult. Both Szucs (63) and Karow (31) indicate that the collected mycelium must be washed thoroughly to remove the residual fluid from the first stage of the fermentation. While the mold cells appear to withstand a minimum, measurements (43) have indicated that ability to oxidize glucose is reduced after even a short treatment. and no doubt too rough treatment will result in considerable killing of the mycelial cells. Application of the two-stage process to large scale fermentation practice has not been reported, and undoubtedly unexpected problems will be found, especially if other organisms are to be kept out of the fermenters.

Application of the "continuous fermentation" technique or the "slow-feed" technique to this fermentation process has not been reported, but, since it has been used successfully in other mold fermentations operated under submerged conditions, it seems adapted to this fermentation. In one variation of the former technique medium is added periodically to the fermentation vessel, and an equal volume is removed simultaneously. In the latter method a concentrated solution of substrate is added periodically to replace that fermented. Both of these practices appear to reduce the time necessary for the production of acid from a given quantity of medium.

Mechanism of Mycological Citric Acid Production

Chemical Changes Occurring During the Fermentation. The chemical changes occurring during fermentation of a synthetic medium in surface culture have been studied by several investigators (44, 73). Similar studies have been made with high- and low-yielding strains of *A. niger* in fermentations of a sucrose medium in submerged culture, with the essential data summarized in Figures 3 and 4. It may be seen that while some differences exist between the types of fermentation practice, greater difference were observed between the two cultures used. The low-yielding culture fermented the available sucrose at a much slower rate than the high-yielding culture, and the total acid formation rate was much slower with the former culture. Perhaps this indicates a more complete oxidation of the carbohydrate, since the curve representing the oxygen demand is much more drawn out. Only traces of oxalic acid were formed by either of the cultures. However, gluconic acid, identified by the benzimidazole derivative, was found in the early stages of the fermentation by the high-yielding culture and was not noted in the media fermented by the low-yielding culture. Perhaps this is the non-citric acid noted during the early part of the fermentation period. Gluconic acid could not be found during the latter part of the fermentation period.

Role of Carbon Dioxide. The role of carbon dioxide in this fermentation has been the subject of much speculation. Use of it, containing the isotopic forms of carbon (C^{11} and C^{14}, radioactive; C^{13}, stable type), has enabled investigators to trace the utilization of this component. Little evidence has been presented, however, that it plays a major role in citric acid formation. Foster *et al.* (24), on the basis of an experiment utilizing $C^{11}O_2$ (half-life of 20 min.), have proposed that it is incorporated in the carboxyl groups of the citric acid formed. However, the evidence is not well established, for the organism was grown only 20 minutes in the presence of air enriched with $C^{11}O_2$, and this brown-spored culture of *A. niger*, later identified as *A. wentii* by Karow (31) who obtained best results when oxygen was used as the aerating gas mixture, would form traces of citric acid (less than 0.01 mg. per ml) only during this interval when grown under the best of conditions. El-Kerdany (23), working with $C^{13}O_2$, has reported that in surface culture carbon dioxide is incorporated into the mycelium and the carboxyl groups of the citric acid formed. The extent of incorporation was not determined. Martin and Wilson (37) have given a preliminary report on the incorporation of carbon dioxide into citric acid when the organism is grown on a synthetic medium in submerged culture, and found the "tagged" carbon in the carboxyl groups of the citric acid. They suggested that less than 10 per cent of the citric acid formed contains the carbon from the carbon dioxide. Until the magnitude of the fixation is determined it is rather valueless to speculate in which reactions the carbon dioxide could participate.

Intermediates in Citric Acid Formation. The increase in citric acid production following addition of certain carbon-containing compounds to growing cultures has been presented as evidence that these compounds are intermediates in the formation of citric acid. The studies in surface culture have been the basis of many theories and have been summarized (51, 68). The studies in submerged culture (47) have indicated that acetate and ethanol will increase the quantity of citric acid formed when they are added to growing cultures. However, these substances may be merely useful carbon sources and may not act as intermediates in citric acid formation. Addition of small quantities of oxalic acid, tartaric acid or hydroxyisobutyric acid also resulted in increased acid production. Undoubtedly these compounds acted to form biologically unavailable complexes of certain metallic ions present in the media and thus probably reduced the mycological degradation of the citric acid (20, 47). The addition of these acids and the resulting increase in citric acid production can not be used as indication that these acids serve as intermediates in the production of the citric acid.

Summary

The literature concerning the mycological process of citric acid production in submerged culture has so far been confined to reports of laboratory experiments; details regarding commercial production are not a matter of public information. These reports indicate that the problems associated with development of the method concern selection of mold cultures, preparation of inocula, selection of media and methods of aeration. They also show that yields of citric acid have been obtained on a laboratory scale by the submerged culture method that are very similar to those obtained by the longer established surface culture procedure, namely, 70 grams of citric acid from the fermentation of 100 grams of carbohydrate.

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Utilization Abstract

Citrus Waste Oil. In the spring of 1947 the Hutchman Company of Lakeland, Fla., began operating the only plant of its kind for extracting oil from citrus waste, and in 1949 processed as much as four tank cars of citrus seed oil in a single month. At the present time, the seeds, after removal from the waste, are processed into approximately one-third oil for use in the manufacture of plastics, resins and medicinals; one-half into cattle meal; and one-sixth into hulls to be ground for use as a fertilizer conditioner. (J. E. Hutchman, *Chemurgic Digest 8(9): 4. 1949*).

Research on the Improvement of Turpentine Practices

The age-old turpentine industry is being modernized by a three-fold research attack involving advances in extraction techniques through chemical stimulation procedures; the selection, breeding and propagation of high-yielding turpentine pines; and engineering research on equipment used in woods operations.

ALBERT G. SNOW, JR.[1]

One of the most colorful segments of American forest enterprise is the gum naval stores industry of the deep South. The industry centers around the solitary "chipper" who winds his way through swamps and saw-palmettoes, wounding thousands of trees once each week. He repeats what his father and grandfather probably did before him. However, the naval stores industry must compete with newer industries for manpower, and its products must be marketed in competition with those of modern chemical industries. It was inevitable, therefore, that technological progress should come to the turpentine woods, even though somewhat tardily, and attention focus on the woods worker who taps the trees.

History

For a proper understanding of the technological problems of the naval stores industry, it is well to examine the industry's deep roots in history and tradition.

Pine pitch has long been a trade article in commerce, and its early use in ship construction and rigging preservation led to the present name of "Naval Stores". The colorful early history of the development of the naval stores industry has been interestingly presented by Ostrom (7). He started with a description of the use of pitch during the period 315 to 166 BC, and traced the changes in this ancient industry through to modern times. In those early days the pitch used in wooden ship construction was derived from the tar obtained from resinous woods during slow combustion. This relatively crude product was used throughout the centuries until the early eighteen-hundreds.

Production of tar and pitch in this country dates back to the days of the early colonial settlers, starting in Nova Scotia (1606) and spreading to the Carolinas. Little turpentining, as practiced today, was done in the deep South prior to 1830. When it was found that longleaf pine (*Pinus palustris* Mill.) would produce abundant quantities of gum, the industry rapidly spread throughout the longleaf belt from the Carolinas to Texas. At the present time the great bulk of production is from the second-growth stands of Georgia and Florida.

The earliest large-scale method of gum collection involved cutting a hole, or "box", in the base of large trees in the virgin forest of that time. This crude and inefficient system continued without change for many years. About the time of the transition from the use of virgin to second-growth timber one of the few great advances in gum-collecting techniques was made. In 1904, following sporadic attempts in the use of cups and gutters, the Herty system of using metal gutters, and cups of various types, was extensively introduced. This basic system is still in use today.

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About 1834 the first copper kettles were brought to North Carolina, and this marked the beginning of the separation of turpentine and rosin in this country on any large scale. Formerly either the crude gum, or tar and pitch, was put in barrels and shipped abroad for processing. At first the raw gum was transported to the coastal towns by river, but later hundreds of small direct-fire turpentine stills became widely scattered throughout the gum belt. Shortly after organized research on better stilling methods was begun in 1926 by the Bureau of Chemistry and Soils (now Bureau of Agricultural and Industrial Chemistry), "steam-still" processing came into use. A much better product was obtained, particularly after the introduction of a process for diluting, filtering and washing the crude gum before stilling. Now about 90 percent of the crude gum produced is processed in modern steam stills.

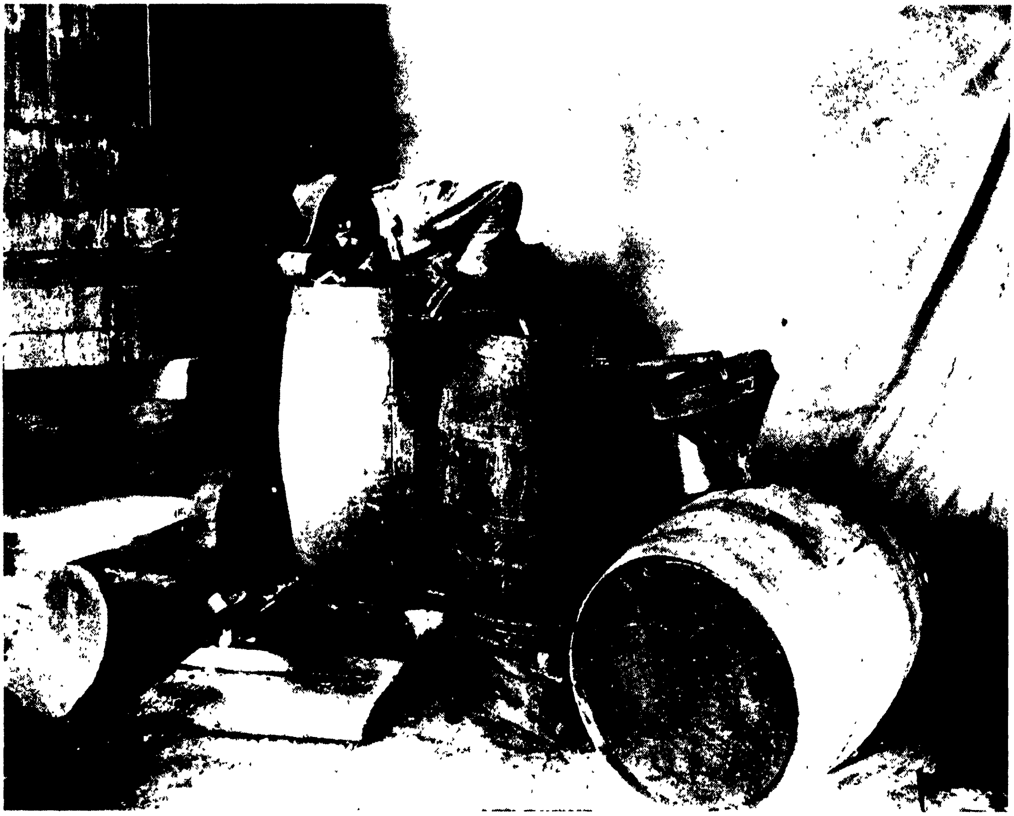

FIG. 1. Old style of separating turpentine and rosin by "sounding" the worm outlet of a fire still to determine relative temperature.

Uses of Naval Stores Products

The materials derived from the oleoresin flowing from wounded pines find their way into a multitude of prod-

TABLE 1

CONSUMPTION OF ROSIN BY U. S. INDUSTRIES, APRIL 1, 1947 TO MARCH 31, 1948

Consuming Industry	*Number of drums**
Chemicals & Pharmaceuticals	350,103
Paper & Paper Size	347,162
Ester Gum & Synthetic Resins	257,929
Soap	144,090
Paint, Varnish & Lacquer	112,890
Linoleum & Floor Coverings	33,532
Adhesives & Plastics	18,095
Rubber	17,741
Oils & Greases	13,193
Foundries & Supplies	10,004
Printing Ink	7,530
Shoe Polish	5,166
Railroads & Shipyards	4,653
Insecticides & Disinfectants	3,338
Asphaltic Products	1,632
Matches	1,121
Abattoirs	618
Automobiles & Wagons	219
Furniture	6
Other Industries	3,717
Total Reported	1,332,739
Not Accounted for	11,539
Total Consumption	1,344,278

* Each 520 lbs. net.

TABLE 2

CONSUMPTION OF TURPENTINE BY U. S. INDUSTRIES, APRIL 1, 1947 TO MARCH 31, 1948

Consuming Industry	*Number of barrels**
Chemicals & Pharmaceuticals	96,878
Ester Gum & Synthetic Resins	17,178
Paint, Varnish & Lacquer	15,048
Railroads & Shipyards	4,910
Shoe Polish & Materials	4,143
Foundries & Supplies	882
Asphaltic Products	449
Rubber	357
Adhesives & Plastics	166
Printing Ink	154
Furniture	153
Insecticides & Disinfectants	125
Automobiles & Wagons	74
Oils & Greases	25
Linoleum & Floor Covering	1
Other Industries	116
Total Reported	140,059
Not Accounted For	325,164
Total Consumption	465,773

* Each 50 gallons.

ucts in everyday use. The rosin consumers are listed in Table 1. Three of these also head the list for turpentine consumption given in Table 2. However, *you* are one of the unseen members of the turpentine group, since most of the 325,164 barrels of turpentine listed as "Not accounted for" goes into the retail trade in small bottles found on the shelves of nearly every conceivable type of store. A bottle of "Gum spirits of turpentine" can be found in a host of places between the garage of an office worker in Florida and an Eskimo igloo in Alaska.

How Pine Gum is Produced

Oleoresin, the gum exuded from wounded pine trees, is derived on a commercial basis in this country from two species, slash pine (*Pinus caribaea* Morelet) and longleaf pine (*Pinus palustris* Miller). This gum is composed of two principle fractions, rosin and turpentine, which are separated in processing by simple distillation.

In preparing a tree for turpentining a worker first smooths the bark near the base of a tree with a tool, such as a broadaxe. The next step is to fasten metal gutters or aprons to the tree to guide the flow of gum into the receiving cup. This is done by either inserting these "tins" in broadaxe incisions or by tacking them on the surface of the smoothed bark. A round clay flower-pot-type cup, or flat-bottomed metal cup, is hung below the tins to catch the flow of oleoresin. The "chipper" then proceeds to cut an incision into the tree, about one-half inch deep and one-half inch high, for a distance around the tree of one-third the circumference, with a tool called a "hack". This chipping is done on a weekly schedule, and a total of about 32 "streaks" are made during the season. The "dip" squad empties the cups when full, usually at three- or four-week intervals. The gum is collected in dip buckets, transferred to barrels holding about 435 pounds of crude gum, and these are transported to a central point in "gum buggys"—rubber tired wagons drawn by a mule. In some modern operations a light tractor is used to pull the gum buggy through the woods.

The gum, as it comes from the ends of open resin ducts, is in a liquid state. Some of this gum crystallizes on the "face" below the freshly cut streak and forms a hardened mass called "scrape". This material, which is lower in turpentine content than fresh oleoresin, is collected separately at the end of the season.

Wounding a tree by "chipping" exposes open vertical resin ducts which are part of an interconnecting network of large vertical ducts and smaller more numerous horizontal ducts. The gum continues to come, drop by drop, from the exposed ends of these ducts, and flows until the ducts are gradually closed, perhaps by slow crystallization of the gum. Rechipping is then necessary to renew the flow of oleoresin. The constituents in oleoresin are synthesized in the epithelial cells surrounding the open vertical ducts to replace that removed during turpentining.

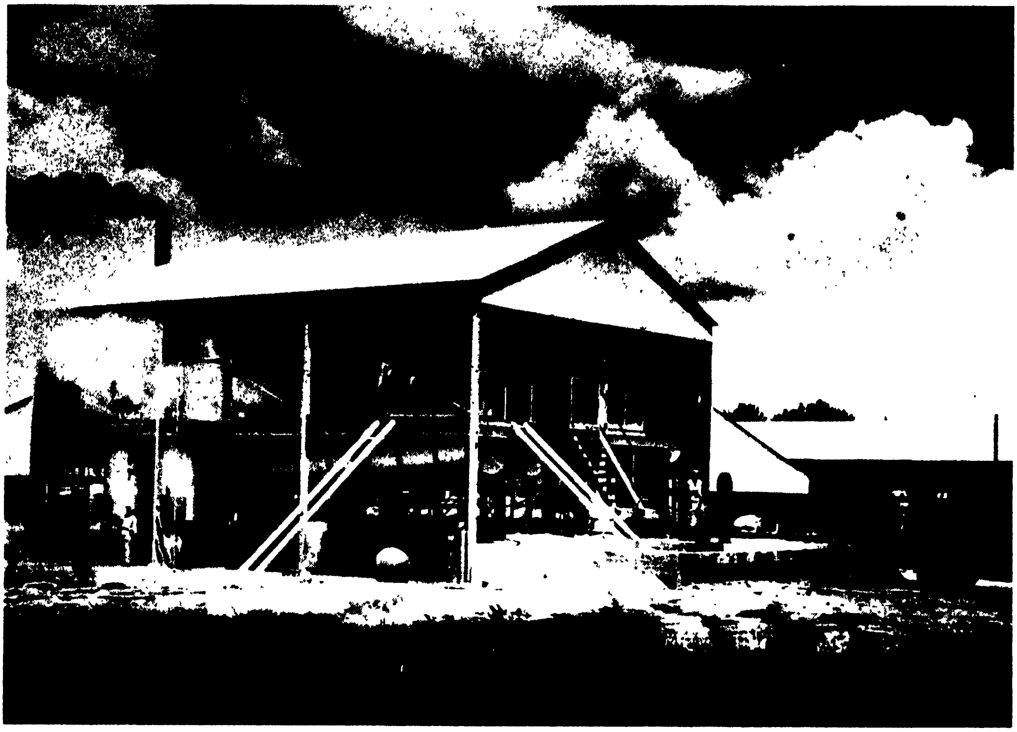

FIG. 2. A modern steam plant for processing pine gum.

At central modern steam stills the raw gum is dumped into vats, then heated and diluted with turpentine to facilitate its movement through pipes. During processing the gum is filtered and washed before going into the still. The temperature of the mixture is raised to the point where the turpentine is volatilized and collected through a condenser. The residual rosin is then usually drained into metal drums and allowed to cool to a clear brittle hardness. In some cases the hot rosin is pumped into special heated tank cars and rushed, in a liquid state, to the plants utilizing rosin on a large scale.

Economics

The gum naval stores industry, with its 43 million dollar income in 1947, and its more than 8,000 gum-producers, is an important segment of the economy of the South. The droplets of oleoresin coming from individual resin ducts less than the size of the shank of a pin accumulated to a total of over 1,350,000 barrels of gum during the 1947 season. It took over 72 million trees to produce this total amount of raw gum. This means an average of 8.1 pounds of gum, worth about 58 cents, from each tree.

This value from each tree each year for five to ten years or more looks like mighty good business, since there is still some wood value in the tree after it is no longer useable for turpentining. However, customary methods of turpentining require so much hand labor that the net income is only a small portion of the gross value of the gum. For instance, in the old days of virgin timber the trees were large and fairly closely spaced. A chipper in those days could handle up to 10,000 "boxes" per week; now with scattered second-growth timber of smaller size, the task for a chipper is about 5,000 "faces" per week. Thus the workers' efficiency is greatly reduced. It is estimated that workers must walk about 3,000 miles to turpentine 10,000 trees for a full season, taking care of all essential operations of cup hanging, chipping, gum dipping and scrape collection (11).

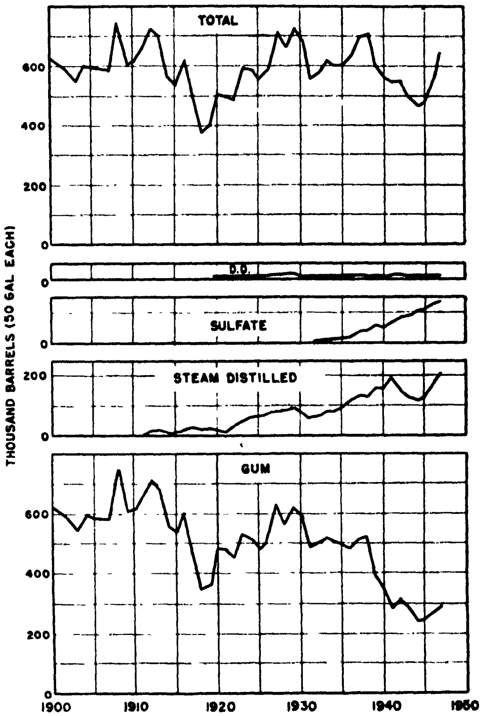

FIG. 4. Trend of production of turpentine in the United States, by types (D. D. represents destructively distilled).

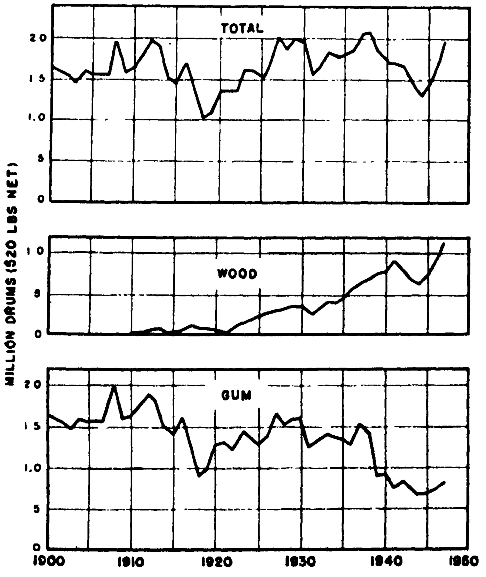

FIG. 3. Trend of production of rosin in the United States, by types.

The peak production of 750,000 units[2] in 1908 marked the maximum naval stores utilization of the original virgin timber. Thereafter the gradual average decline in production coincided with lower demand, low prices, decreased availability of large trees and greater labor costs per unit of gum produced. Following the temporary production spurt just afer World War I, the same production decline continued.

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[2] A gum naval stores unit is one barrel (50 gal.) of turpentine and 2-2/3 drums (520 lbs. net weight each) of rosin.

Another factor contributing to price declines was the gradually increased competition afforded by substitute products. A cheap substitute for turpentine as a paint thinner and solvent was available in the petroleum derivative "mineral spirits". Rosin is also produced much more cheaply from stumpwood, the old stumps of the virgin longleaf timber; it is estimated that 25 or more years supply of stumpwood is still available. At the present time tall oil, a recovered by-product of the sulphate process in manufacturing paper from pine wood, is being utilized on a much larger scale, and because of its cheaper price is fast taking over certain rosin markets. It is estimated that two million pounds were used in 1943 for paints, varnishes and floor coverings, while 32 million pounds were used in 1947 for the same purpose.

During World War II the demand for turpentine and rosin exceeded the supply. The goal of 350,000 units of gum naval stores during the fourth year of the war was not met; only 250,000 units were produced. The acute labor shortage was the principal cause of this failure, since gum production is still largely dependent on labor. A continuing labor movement from the turpentine camps to pulpwood operations has taken place since the war. Thus it is evident that if the gum naval stores industry is to be maintained under increasing competition for labor, new techniques for increasing the efficiency of production in the woods are urgently needed.

To meet this demand for increased efficiency in gum naval stores production, the U. S. Forest Service intensified its meager research program in naval stores shortly after the beginning of the recent World War. The industry now has a much better outlook because of the present and future results of three lines of research attack: advances in extraction techniques through chemical stimulation procedures; selection, breeding and propagation of high-yielding turpentine pines; and engineering research on equipment used in woods operations.

Research Progress

Sporadic individual research efforts by Charles Herty started about the turn of the present century, while organized research in naval stores was delayed until studies were commenced at Starke, Florida, in 1922 by the Southern Forest Experiment Station of the United States Forest Service. The program was concentrated on improving extraction techniques in the woods. They approached the problems by determining optimum depths and heights of chipping, tree sizes best suited to economical turpentining, optimum number of faces per tree, methods of cup and gutter installations, frequency of chipping, and a host of related studies. Much progress was made and many practical techniques worked out and recommended for industrial application.

One big advance was made in delimiting the minimum size of tree to be turpentined. When gum prices were high and large virgin trees scare, the operator turned to very small trees. It is said that some of the trees were so small it took two men to work a tree—one to hold it steady while the other chipped. This exaggeration emphasized the fact that the turpentine men did work very small trees—some as small as five inches in diameter—and actually the gum yield on these small trees was not of sufficient value to pay for the cost of operation. Largely as a result of early concrete re-

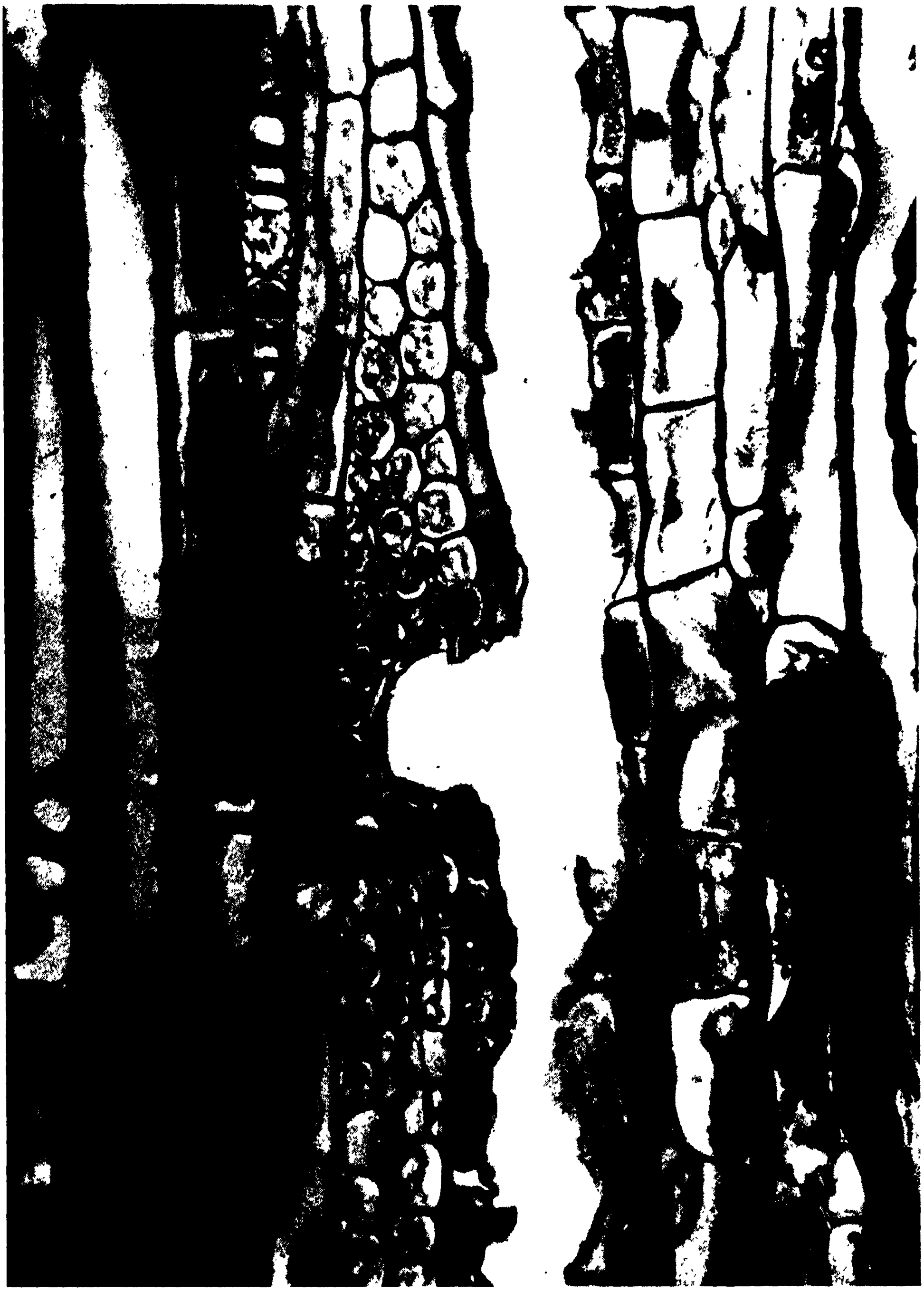

FIG. 5. Meeting ground of a large vertical resin duct and the duct of a horizontal ray in tangential section.

search results the minimum size of tree for profitable tapping was set at nine inches in diameter breast high. The industry rapidly came to adhere to this precept when it was written into the Naval Stores Conservation Program of the Department of Agriculture in 1936.

The original concept, when virgin trees were being worked, was to chip "knee deep and belly wide". Later research showed that deep chipping, on second-growth trees particularly, did not yield appreciably greater quantities of gum than shallow chipping. The deeply chipped trees were also subject to excessive wind-throw. At the same time chipping a streak from three-fourths to one inch in height not only used up the tree faster but yielded less gum over a period of years. The optimum depth was found to be about one-half inch into the wood, and the best chipping height was between three-eighths and one-half inch. In this way the trees could be worked for a much longer period of time and were subject to less wind breakage, while yielding sufficient quantities of gum.

Another uneconomical practice, carried over from the early days of abundant and large virgin timber, was the use of more than one face on small trees. Research results showed that when more than one face was put on trees under about 12 inches d.b.h., the yields per face were not sufficient over a period of time to allow any profit. The chipper was paid on the basis of the number of faces chipped, and when gum yields were low because of too many cups per tree, the yield from these "overcupped" trees was too low to pay for the cost of chipping and dipping.

Chipping frequency is important in obtaining maximum gum yields. When a streak is freshly cut, the gum starts to flow almost immediately. The rate of gum flow reaches a maximum the first day, and continues at this rate for two or three days before a decline takes place. This is aside from diurnal fluctuations, where the gum-flow rate starts to increase in the early morning, reaches a peak about 9 a.m., slows up to a lower rate by evening and is low overnight. After about seven days the rate of flow is very low, and a fresh streak is then cut. Usually the trees are apportioned among the workers at the beginning of the season, and they are expected to chip these trees once a week from March into November. Some operators chip their trees at irregular intervals during the winter on an average monthly schedule.

Relatively recent studies have indicated that a saving of as much as 30% in the first year's gum yield can be attained by careful methods of installing cups and inserting the metal gutters which are used to direct the flow of gum. Many trees on commercial operations are blazed through the bark and wood for setting cups, and are deeply incised with a broadax for the insertion of gutters and "aprons". Such treatment renders the trees more susceptible to wind-throw and interferes with normal conduction of water, nutrients and gum. It is good practice not to let any gutter incisions exceed the depth to be chipped during the course of the naval stores season. This applies to both the old established practice of "deep chipping" (about one-half inch deep) and the newer techniques of "bark-depth" chipping where chemical stimulants are used.

Modern Advances in Gum Extraction

Intensive research efforts were started shortly after the beginning of World War II. The cooperative effort in three main types of studies resulted in finding methods to increase both gum production and the efficiency of woods work. Fundamental studies were made in the physiology and anatomy of factors affecting the flow of oleoresin. Findings of possible practical application from these studies were next tested in carefully controlled field experiments where the yields from calibrated trees were individually measured at frequent intervals. The most promising treatments were then tested in pilot-plant studies where selected stands of trees were subjected to these treatments, provided with standard controls, and the work done by actual turpentine operators on their own land under existing commercial conditions. In this way new practical turpentining methods were found, tested and tentatively proved in a relatively short time.

Chemical Stimulation. Delimiting the best techniques for prolonging gum flow by application of chemicals to the fresh wounds has been one of the major recent contributions of research to the future well-being of the naval stores industry. The development of chemical

FIG. 6. Punch-wound system for preliminary tests of chemicals that might stimulate the flow of oleoresin.

stimulation possibilities has been described by Ostrom (8) who mentioned the initial use of chemicals to stimulate gum flow in the early thirties in Europe, and the modest research in this country prior to the last World War.

Initial studies in gum-flow stimulation, made at the Olustee Experimental Forest near Lake City, Florida, indicated that sulphuric acid, hydrochloric and possibly sodium hydroxide would stimulate the flow of gum, particularly in slash pine (*Pinus caribaea* Morelet). This was the status of our knowledge at the start of World War II. The immediate need for increased gum production led to an expanded research program. First, we needed to know the optimum concentration of a specific chemical that would work on slash pine and longleaf pine. It was found, considering availability of chemical, cost and its effect, that sulphuric acid in concentration of 40 to 60% was best for slash and longleaf pine, respectively. Recent work has shown that a concentration of 50% may be feasible to use on both species.

In practice about one cubic centimeter of the proper strength acid is sprayed on a freshly cut streak with the applied liquid hitting the wound at the junction of bark and wood in the cambium region clear across the face. In contrast to regular untreated chipping, the rate of gum flow increases more sharply in the case of acid treatment and continues at this accelerated rate for a much longer period of time. The rate of gum flow slows down markedly with regular untreated chipping after four or five days, while with acid the increased rate continues with only slight reduction for ten days or more and is still appreciable even into the third week.

The action of chemical stimulants in accelerating and prolonging gum flow is intimately associated with the small resin ducts from which the droplets of oleoresin exude. As described by Ostrom (8): "These ducts extend vertically in the wood and horizontally toward the center of the tree in both bark and wood. Where the vertical and horizontal ducts cross, their cavities join, as in the plumbing system of a building. All of the ducts are lined with thin-walled, brick shaped parenchyma cells which, in the wood, contrast sharply with the long, thick-walled wood fibers. After treatment with a strong acid, the tender cells lining the ducts are collapsed near the site of treatment, and the duct channels are correspondingly enlarged. It is reasonable to suppose that as a result, the gum can exude more rapidly from the ducts, and that the enlarged ends of the ducts may be less readily closed than normal ducts by the hardening of the gum at the outlets.

"Another effect exerted chiefly by strong acids is the destruction of the tender new cells in the growing region or cambium which lies between the wood and the bark. Over a period of several days the acid works up into this region and causes a splitting away of the bark from the wood, one-fourth to one-half inch above the wound. This process probably serves to tap new horizontal ducts, several hundred of which cross each square inch of the cabmium. The solutions applied to the wound may also stimulate the process of gum manufacture in purely chemical ways, but the exact nature and relative importance of such effects are not yet known".

Prolongation of gum flow with acid treatment is very important from the standpoint of increased efficiency in turpentining operations. For instance, treatment with sulphuric acid results in 50 to 100% more gum during the first week. The treated streaks continue to yield above-normal quantities of gum during the second and third week after chipping. The gum yield for a two-week period is at least equal to the yield from trees chipped twice without treatment during this time. Thus equal gum yields can be obtained with less labor. At the same time, when trees are chipped only every two weeks, the working life of a tree is increased. However, the woodland owner also has the alternative of chipping and treating at biweekly intervals for the normal five-year period with expectations of regular gum yields, and because of the lower total face height he can have more clear bole for lumber production.

Another recent advance in chipping technique was the discovery that when acid is used, removing only the bark down to the wood (bark chipping) will result in gum yields comparable to those from regular chipping where a half-inch strip of wood is cut from the tree. This new method requires less exertion, appeals to laborers and is considerably easier to teach to inexperienced men than the old style of chipping. Bark chipping also leaves the butt of the tree in better condition for use as pulpwood, poles, ties or lumber. Since no deep incision is made into the wood, it is also possible that the tree will be maintained in a better physiological state for gum production when chipped over a period of years.

Fungus Stimulation. Another approach to increasing the efficiency of gum production in the woods was the discovery that the fungus *Fusarium lateritium* f. *pini* prolongs the flow of gum from infected wounds on several pine species (4, 17). When spore suspensions of this fungus are sprayed on freshly chipped faces of slash or longleaf pines, gum continues to flow without rechipping or treatment for two to eight weeks. This looked like a good practical treatment, provided no damage to the tree or surrounding stand occurred. Studies on possible damage are under way.

There is a catch, however, to the possible practicality of a fungus method to prolong gum flow. The period of prolonged gum flow is not so great after rechipping and reinoculating as it is after the first inoculation. Further work is being done to devise possible practical methods of putting this fungus to work in the turpentine woods.

Selective Cupping. For many years turpentining took precedence over any other tree use in many sections. There are still many timber owners whose primary interest is in turpentining, and wood products from their lands are considered of secondary importance. However, the increased value of the trees for such products as pulpwood, sawlogs, ties, poles and piling, and ready market accessibility have changed the relative importance of turpentining. Now the income from these other outlets sometimes is considerably greater than the gum value.

The old diameter-limit system of cupping, where all trees were tapped down to a definite diameter, precluded the production of higher value trees for lumber production or other uses. The turpentine face, or jumpbutt, was usually cut and left in the woods, or commanded only a small price for fire-wood. This system limits the useable cubic content of wood removed after turpentining and also reduces the grade of the remaining stems of the trees. Also, no provision is made for leaving a stand of high-quality trees properly spaced for future growth. An alternative system —selective cupping (5)—will result in the maintenance of well-stocked stands and production of larger, more profitable trees.

Selective cupping involves marking the trees which should come out of the stand in the next cut, whether it be a thinning, a seed tree cutting or any other type of cutting based on the needs of the stand. Of the marked trees, those large enough are then turpentined before they are cut. As a rule, the best-quality timber trees are left to grow to a larger size before they in turn are turpentined. By this method of selective cupping, turpentining is fitted into its proper place in good forest management aimed at providing the maximum income per acre from gum and wood products combined.

High-Yielding Naval Stores Pines

Another approach to better turpentining methods is through improvement of the individual tree (6). As in any plant community, there are certain individual trees in a stand that grow faster, are of better shape, possesss some disease resistance, or—in the case of turpentine trees—produce more gum. Thus

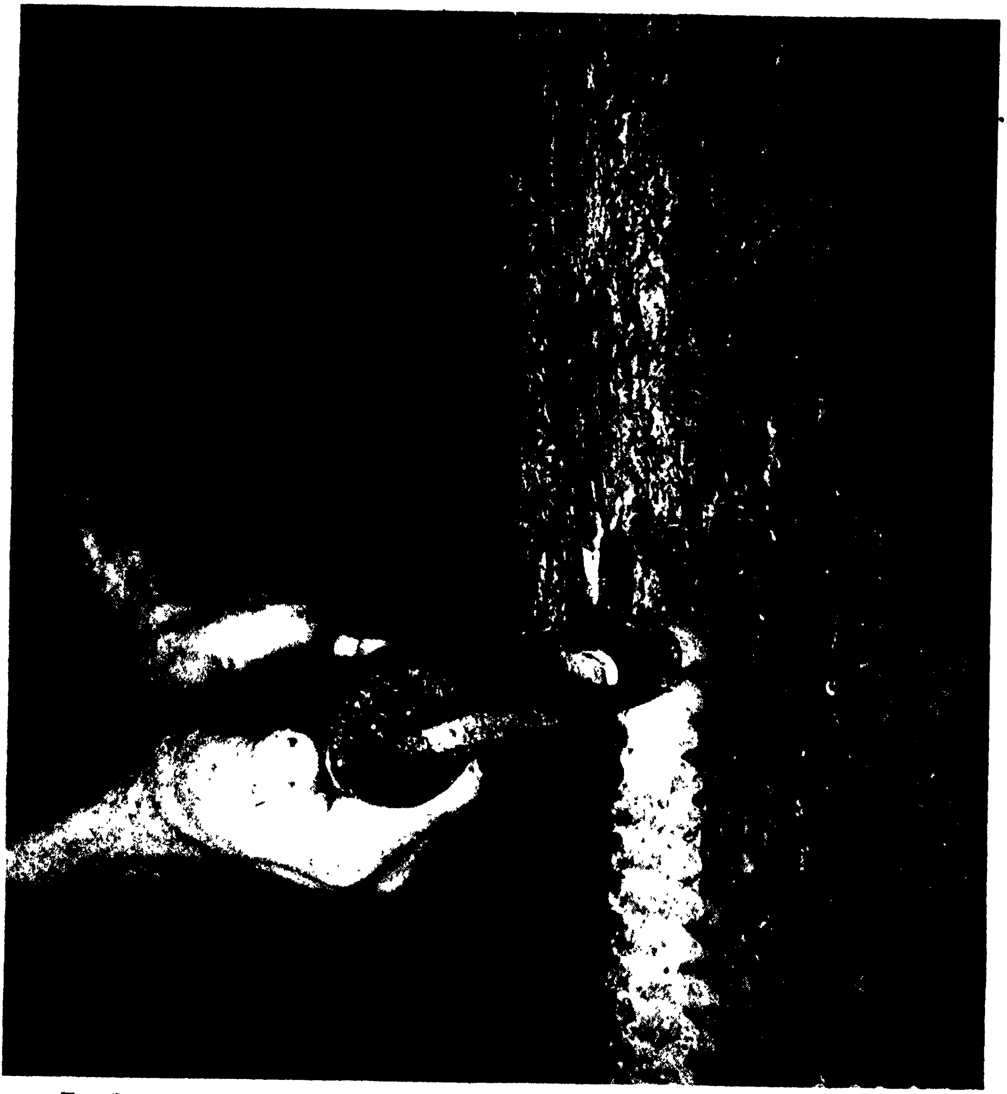

FIG. 7. Regular chipping one-half inch into the tree and one-half inch high.

the same basic approach to any crop improvement program also applies to improvements in trees used for both turpentining and timber growing. This is accomplished through selection and breeding (2). The practical application follows the discovery of suitable propagation techniques. In this phase of naval stores research, early results for field use will not be available. However, the delay is not so long as may be supposed.

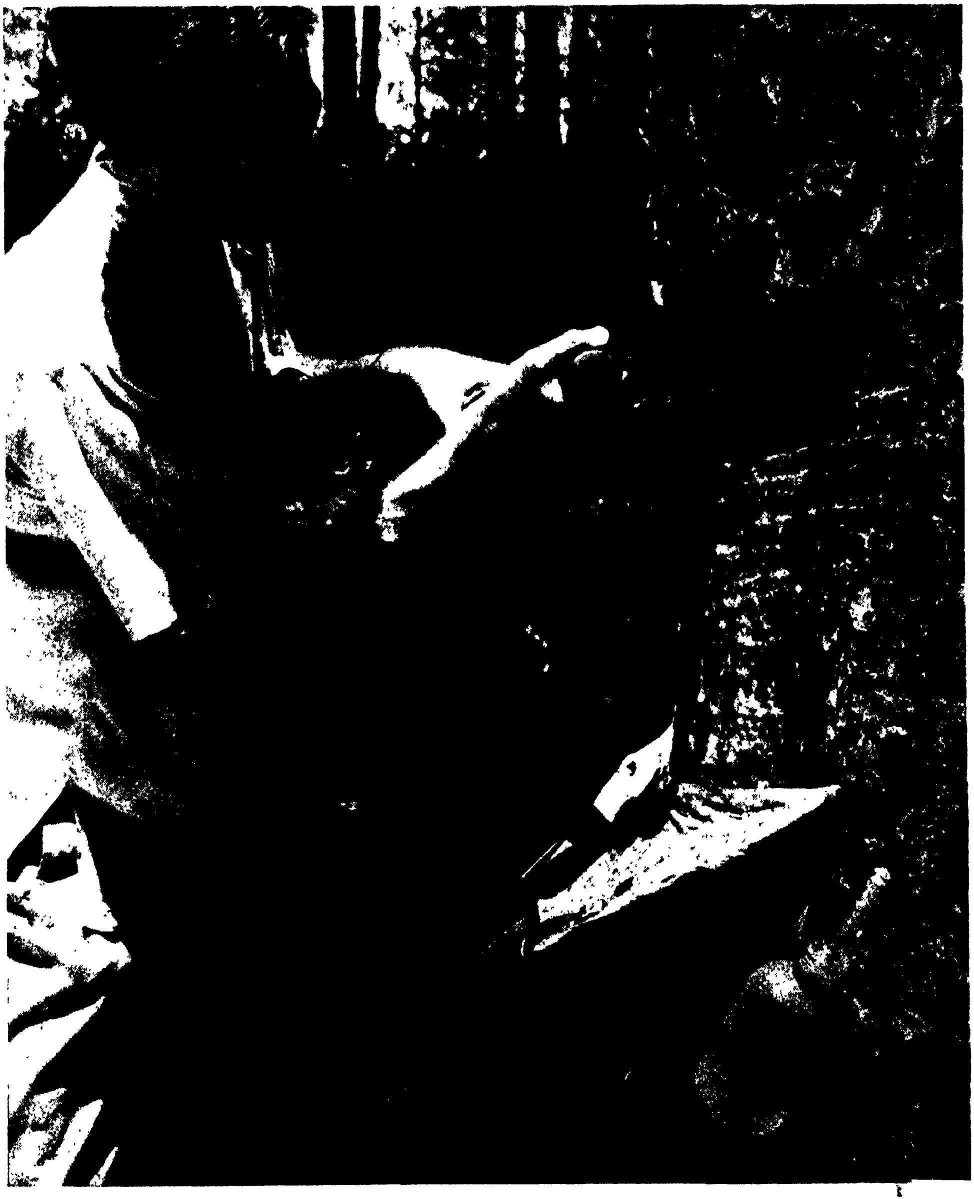

Fig. 8. Bark chipping, with new acid spray gun hung on the end of a gutter, and a cup cover of acid-resistant material to keep chips out of the gum.

Selection. Selection among trees in the natural forests for controlled breeding purposes will be quite generally practiced in forest research for a long time. At present selection among controlled breeding progeny in most forest-tree species is not possible because of lack of material. In the naval stores belt a start in selection has already been made, and a number of individuals have been found that yield two to two-and-one-half times as much gum as the average tree of the same size growing under the same conditions (1). Others were also found that produce less than half the gum yield expected from average trees. Careful yield measurements on individual trees were necessary to establish their relative gum-yielding level. Numerous other trees of the same diameter class were turpentined throughout a season along with the suspected high-yielders. No single or combined external tree characteristics, or environmental factors, were found to set these superior trees apart.

As time and manpower permit, further searches for high-yielding trees, or trees with other valuable characteristics such as good form or fast growth rate, will be undertaken. Aside from this continuing work, the next step in selection is a careful examination of progeny resulting from controlled breeding work. It is expected that microchipping techniques will be developed to differentiate between trees of different yielding abilities while they are still small.

Breeding. The complement of selection is breeding. As pointed out by Dorman (1): "While yield capacity may be greatly increased through the selection and propagation of the best individuals which occur in nature, progress in this direction is limited to the point beyond which no better trees exist in nature. Further increases in yield capacity can be made only through controlled breeding".

Some of the possible crosses have already been made between three tree species—slash (*P. caribbaea* Morelet), longleaf (*P. palustris* Mill.) and loblolly pines (*P. Taeda* L.)—and many of the possible breeding combinations between high, average and low-yielding slash pine trees. The first progeny of these crosses are now growing in field plantations, and when they attain sufficient size they will be tested to determine their relative gum-yield levels. The next steps would be the establishment of nurseries for a source of propagation stock, and controlled breeding in the second generation.

Propagation. Practical means of propagating select turpentining stock is essential to the program of forest-tree improvement. Vegetatively propagated strains of high yielders would initially serve three purposes: first, to establish "seed orchards" of select strains for natural seed production from high yielders; second, to establish nurseries of these select strains for the production of cutting stock; and third, to perpetuate the clone in case of loss of the parent tree.

Most pine species are difficult to propagate vegetatively, particularly when they approach maturity, though methods have been found for some species (3). Cuttings of hard, or southern yellow, pines are particularly difficult to root. Only after numerous trials were some cuttings from older trees rooted. It was found that abundant sunlight and intermittent water spray were especially important, even though many known plant hormones and nutrients were also used. Since the war, work has been speeded up on development of vegetative propagation methods sufficiently simple and effective for large-scale use in commercial nurseries. Much remains to be done before practical methods will be available.

Turpentine Orchards. In the second-growth stands of today the average number of trees per acre being turpentined is about 25; the range is from as few as 15 to as many as 80 trees per acre. A chipper usually handles 1,000 trees per day, and actual time studies

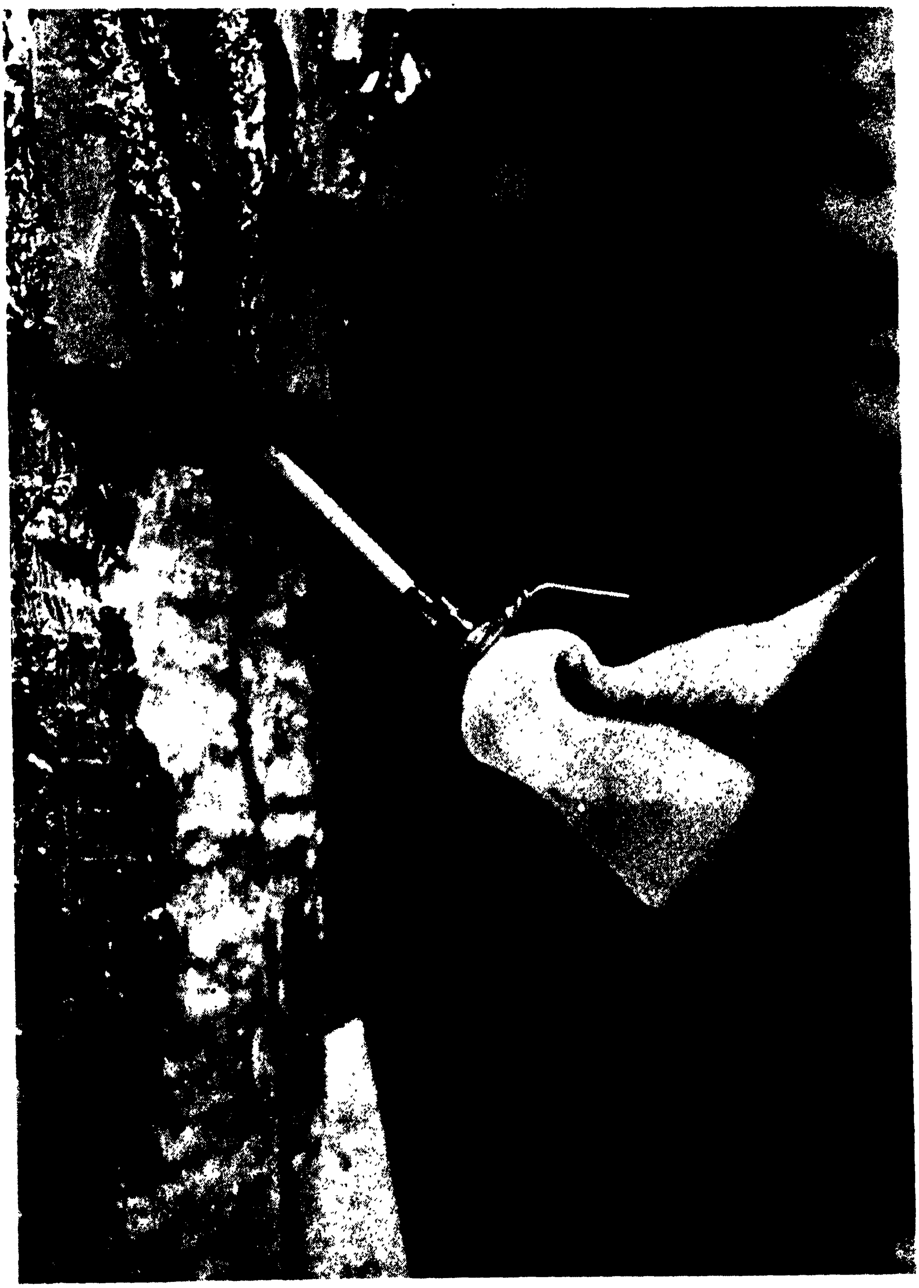

FIG. 9. Newly developed "squeeze bottle" for applying acid to freshly cut streaks.

have shown that about 65% of the chippers' and dippers' time (11) is spent in walking from tree to tree, often through rough ground cover of sawpalmetto and gallberry brush. It is reasonable to expect that if the trees were much closer together, with a minimum of ground cover, the chippers would chip more trees each day and the dippers could dip more gum, thus creating a more efficient operation.

It is believed that a high degree of efficiency can be attained through the establishment of turpentine orchards of high-yielding strains of trees (1). With a 12-by-12-foot spacing there would be about 300 trees to the acre. This is in sharp contrast to the 25-tree average now being worked. And plantations are recognized as being economically feasible, for there are approximately 102,000 acres of hand-planted forests in Florida alone. The walking distance in a plantation would be about one-sixth that now required, which in itself increases the number of trees a chipper could handle. Dipping costs would also be materially reduced, since the dipper would not have to lug a heavy dip bucket so far from tree to tree. The dip wagon could go down the rows of trees and be close to the man with a dip bucket full of gum.

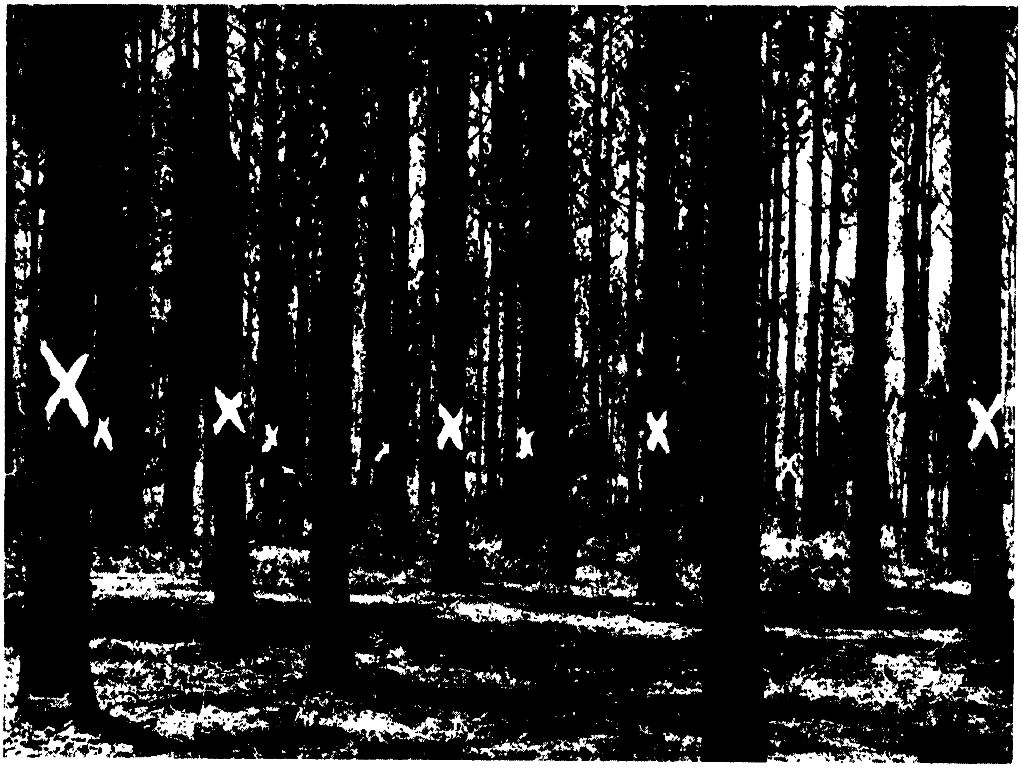

FIG. 10. Selective marking of a timber stand is equivalent to selective cupping for turpentining. Trees marked with crosses are being cupped and will be removed in the next thinning.

Gum yields average about eight pounds of gum per tree for a season, which amounts to about 200 pounds per acre if 25 trees are worked. If we assume that about 250 out of the 300 trees per acre in a plantation attain workable size at the same time, then the yields

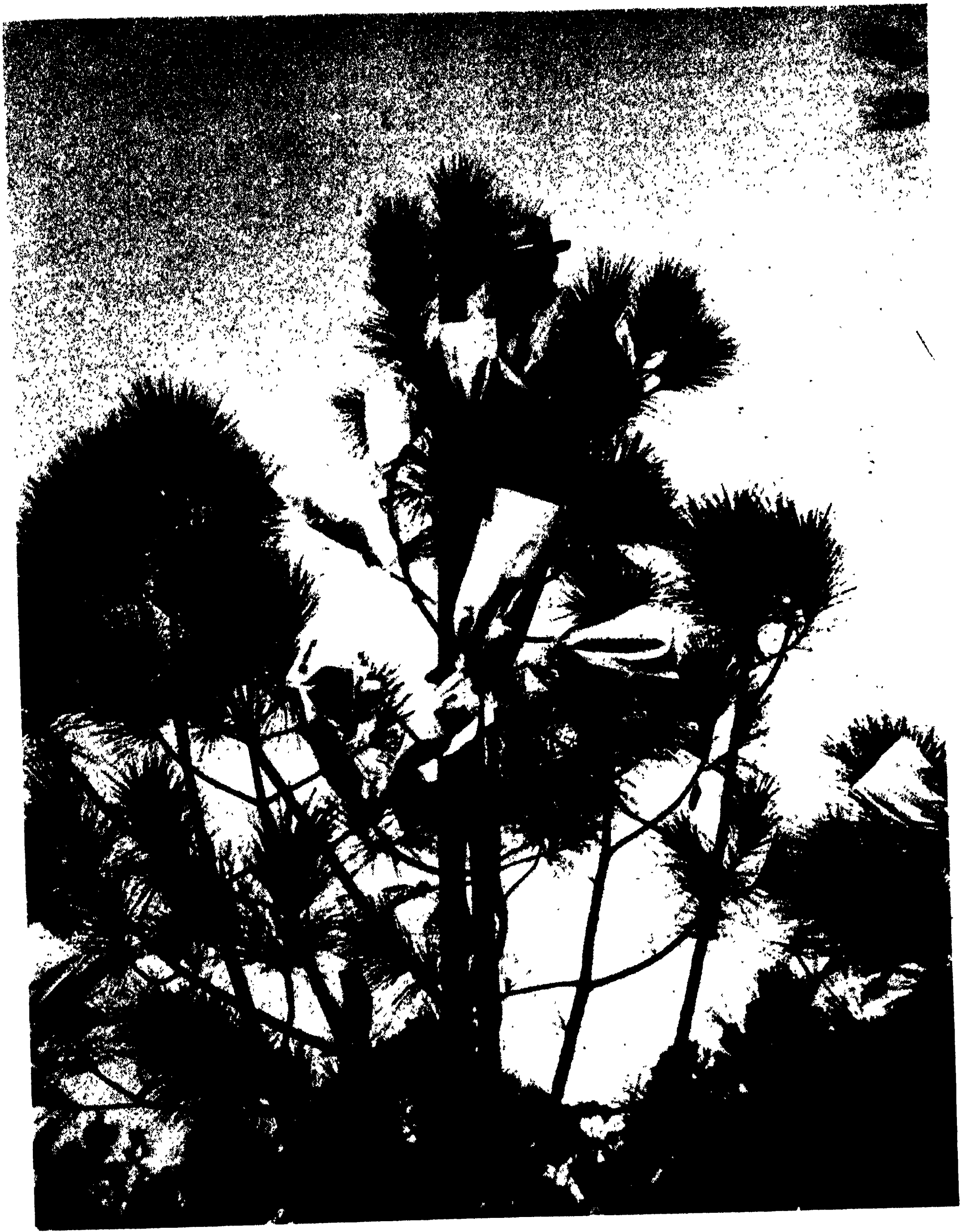

Fig. 11. Controlled breeding in the top of a slash pine tree.

should be about 2,000 pounds of gum per acre per year, ten times as much. Further, if the plantation consisted of a "pedigreed" stock of high-yielding strain producing twice the average amount of gum per year, the per-acre yield theoretically would be around two tons in contrast to the present 200-pound yield per acre per year.

This picture of the possibilities of turpentine orchards of the future appears optimistic, since it will be at least 25 years before this dream could be attained in practice, but the potentialities

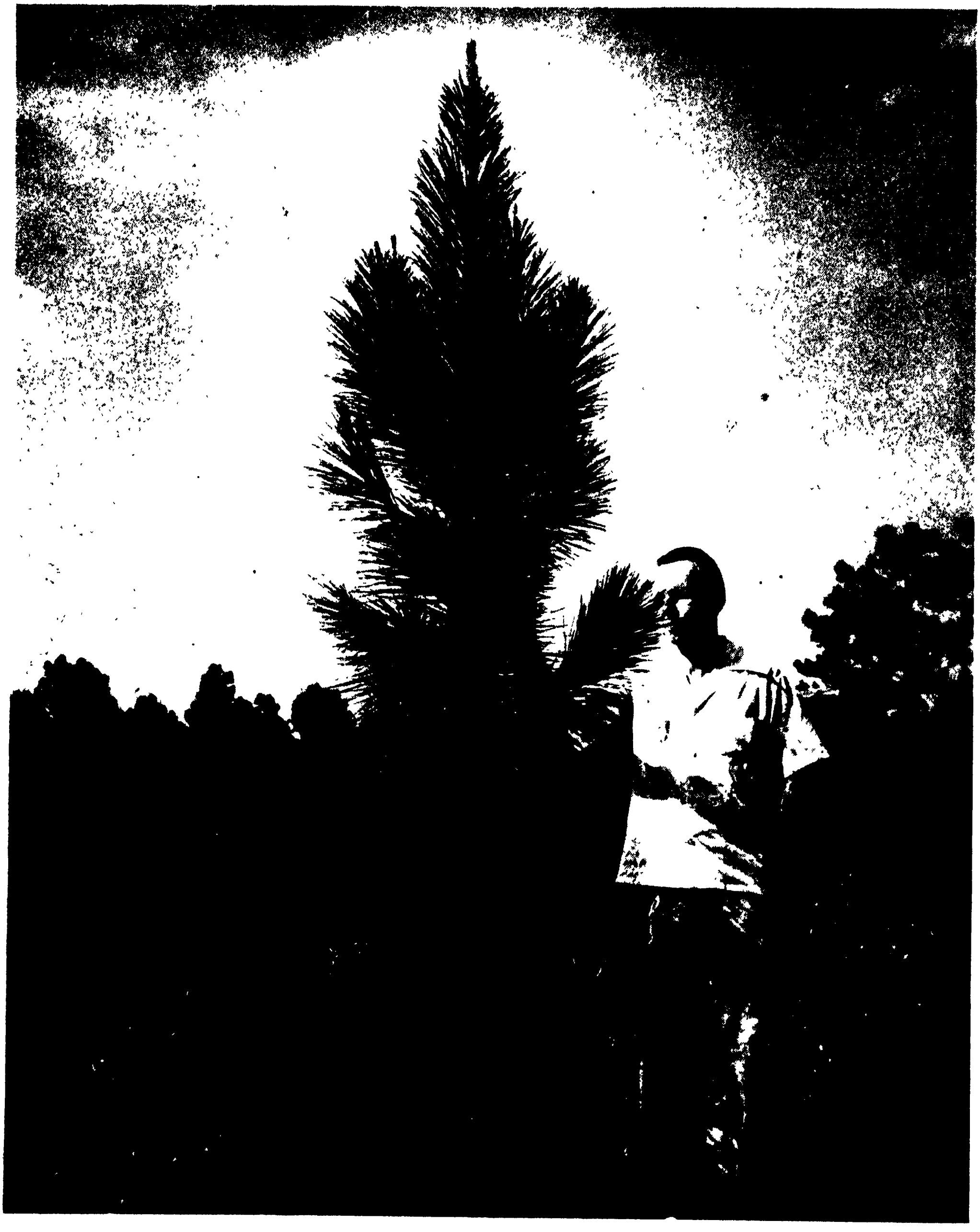

FIG. 12. A rooted cutting of slash pine four years after leaving the propagating bed.

are still there. Yields in actual practice, though much higher than at present, will probably be lower than the quoted figure because optimum spacing might be much greater, with fewer trees per acre. The details of selection, breeding and propagation will have to be further perfected and made practical before such per acre yields will be obtained.

Equipment and Mechanization

Mechanization has been the salvation of many an industry. Those of an agricultural nature are no exception. In most cases the need for mechanization has arisen in industries requiring large amounts of hand labor. The naval stores industry is still primarily dependent on hand labor in the woods (10).

Certain aspects of woods work in turpentine operations lend themselves well to being mechanized. Current thought emphasizes using mechanical means for chipping the tree, dipping the gum and transportation of both the gum and labor. A common power source on a suitable self-propelled vehicle, to combine all these operations during one visit, seems within the realm of possibility. In this way few visits to a tree would have to be made, each operation would be much more efficient and much less labor would be required.

There are also many other phases of woods work, though less spectacular than a powered vehicle, where competent engineers could work out valuable contributions to increased efficiency in gum extraction. Among these may be included such things as larger cups, special gutter systems, better chipping tools, efficient chemical spraying devices, time-saving dipping methods, and relatively more efficient and cheaper transportation facilities. All of these factors are being considered in the mechanization studies in turpentining currently under way by the U. S. Forest Service in cooperation with the Engineering and Industrial Experiment Station of the University of Florida.

One difficult hurdle has been overcome in the development of an efficient spray gun. The use of chemical stimulants requires an acid-proof and shatter-proof acid applicator that can be operated by one hand. The adoption of chemical stimulation has been accelerated by the perfection of a very simple "squeeze gun" made of flexible plastic (12). Progress has also been made on a dual-purpose tool incorporating this new plastic spray gun in the handle of the hack used for chipping.

Future Possibilities

The naval stores industry is again at another crucial point in its history. A standard barrel of crude gum is now selling for about $24.00 at a local point, in contrast to an average of about $30.00 for the 1947 season. This price reduction occurred in the face of continuing increases in the cost of materials and labor during the past year. The industry's future program must follow several courses. Woods operations must be made much more efficient through adoption of modern turpentining practices. Portions of the woods operations may have to be mechanized to reduce costs. Land owners must also look to the future and integrate turpentining and sound forest management. This step will involve in some instances "high intensity" management with improved tree types utilized to the fullest extent. Turpentining can continue to pay dividends only if the results of modern research are put into practice.

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Utilization Abstracts

Rutin. Many years ago a Hungarian biochemist, Albert Szent-Gyorgyi, observed certain medical benefits obtained by using extracts of citrus fruits and red peppers. The effective principal was not isolated or identified, but was named "vitamin P" by Szent-Gyorgyi. Many years later two physicians at the Medical School of the University of Pennsylvania were interested in the weakened capillaries associated with high blood pressure, a condition that sometimes results in brain or retinal hemorrhage. Capillary fragility was one of the conditions alleviated by vitamin P, and certain chemical relationships between vitamin P and rutin, a compound widely distributed in the plant kingdom and known to scientists for more than a century, impressed these investigators. Rutin was thereupon isolated in usable quantity from tobacco by chemists at the Eastern Regional Research Laboratory, Wyndmoor, Pa., a suburb of Philadelphia and was effectively used by the physicians in restoring weakened capillaries to normal strength. Thus a very close similarity if not actual identity between vitamin P and rutin was established.

With a resultant demand for the drug a few pharmaceutical manufacturers began to produce the material, but it soon became apparent that tobacco was too costly as a raw material. After testing all potential plant sources for their rutin content, Dr. J. F. Couch and his associates at the Regional Laboratory found buckwheat to be the most suitable for commercial production of the drug. One dollar's worth of it, in terms of rutin yield, were found equivalent to $125 worth of tobacco leaf.

Of the several known types and species of buckwheat, Tartary buckwheat has been found to be the best. 50,000 acres of it will be needed to meet the demand for rutin. "At least 15 pharmaceutical companies are now producing rutin in quantity, and a still larger number are processing rutin into dosage forms, principally tablets, for sale through the drug stores on physicians' prescriptions. In addition, rutin is now being prepared in England, France, Holland and China and possibly also in Sweden and Denmark". (J. F. Couch, *Crops & Soils*, June–July, 1949).

Fiber Flax in Oregon[1]

Russia, Poland and the Baltic countries account for about 90% of the world's production of fiber flax, and prior to 1940, 90% of the raw fiber used in the United States was imported from Europe. Today domestic production in the Willamette Valley of Oregon represents a $3 million dollar industry.

DONALD W. FISHLER[2]

Introduction

Linen, the cherished fabric of elegance through the ages, is coveted by many, but few are acquainted with its raw material—fiber flax.

Fiber flax is one of the oldest plant textiles known to man. The ancient Egyptians possessed the knowledge of weaving fine linen, and the Bible makes frequent mention of the use of linen among the Hebrews who regarded it as symbolic of purity and cleanliness. Flax was one of the earliest crops planted by the colonists in North America, and it continued to be one of the leading fiber crops until the invention of the cotton gin in 1793 which cheapened the processing of cotton to such an extent that cotton superseded flax as a source of fiber in the United States. Linen, however, never lost its appeal to the American housewife. Even today imported manufactured linen goods represent a value of over 35 million dollars annually, and during the years just prior to World War II the annual imports of raw flax into the United States ranged from 1,300 to 6,500 tons.

There are two types of flax. One, known as "seed flax," is grown primarily for its oil-bearing seed and produces as a by-product a harsh brittle fiber not suitable for economical spinning. This type is short growing and produces many branches which are conducive to high seed yield. The other type, fiber flax, is grown primarily for its long spinnable fiber but produces seed as an important by-product. The fiber varieties are taller growing than the seed-type varieties and produce small branches near the top of the plant. This article deals with the production and processing of fiber flax in Oregon.

History

The production of fiber flax in Oregon is over a century old. In 1844 Mr. J. B. Kirkwood raised flax near Tualatin, Oregon. The seed for this planting had been carried across the plains during the early period of settlement of the Oregon country. In 1876 flax fiber produced in Oregon and exhibited at the Philadelphia Exposition won the Bronze medal and Certificate of Merit for its outstanding quality. Oregon fiber was then recognized for the first time as being of superior quality. Subsequent to this recognition, many attempts were made to establish the flax industry in Oregon, but little progress was made.

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[1] Published as Technical Paper No. 561 with the approval of the Director of the Oregon Agricultural Experiment Station. Contribution of the Department of Farm Crops. Photos by Leonard Delano Studio.

[2] Agent in the Division of Cotton and Other Fiber Crops and Diseases, BPISAE, U. S. Department of Agriculture. Fiber flax investigations are carried on under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture and the Oregon Agricultural Experiment Station, Corvallis, Oregon.

Agricultural and climatic limitations were not the reasons for the slow development of the Oregon industry; it was due rather to inadequate leadership and to the difficulty of raising capital for building processing facilities.

The people of Oregon are indebted to their State legislature for actually providing impulse to the industry. In 1915 this body appropriated $50,000 for the establishment of a flax-processing plant at the State penitentiary. The main purpose of the appropriation was to encourage, foster and support the Oregon flax industry and also to provide labor for the inmates which would be of a non-competitive nature. Leaders of Oregon agriculture encouraged the legislature to make this initial appropriation, hoping that it would serve as a stimulant for the building of a new industry. Today it is recognized that this original appropriation served as a nucleus from which the industry has grown. The penitentiary plant is still in operation, furnishing employment for the inmates and at the same time providing farmers in the surrounding areas with a suitable market for their flax. Because of the bulkiness of flax plants it is not economically feasible to transport tonnages over great distances. It was apparent, therefore, that the penitentiary plant could serve as a market only to small nearby areas. Many feared that legal barriers might prohibit the sale of fiber which had been partly processed with prison labor and thus destroy a potentially great industry before private capital became interested.

In 1936, through the assistance of the Works Progress Administration, and under the sponsorship of the State of Oregon, three flax-processing mills were constructed in the Willamette Valley. The mill operators found a ready demand for their fiber.

Approximately 90 per cent of the raw flax fiber used in the United States had been imported from European countries prior to 1940. During that year the German war machine rolled across France and the Low Countries, and the Allies no longer had access to these important raw fiber supplies. Excluding Russia, the Axis Powers then controlled 99 per cent of the world's flax-growing areas. This conquest gave the small Oregon industry a chance to expand and to demonstrate again that fiber of the highest quality could be produced in that State.

In 1940 and 1941 four additional mills were built with private capital. In 1942 the strategic importance of flax in the war effort was fully realized. Fortunately the State of Oregon had laid the foundation on which the industry could grow. The United States needed a strong, non-elastic, rot-resistant fiber for parachute webbing and shoe thread. Linen fire hose which would not deteriorate under adverse conditions was in demand. The fishing industry, an essential part of our economic life, required strong and durable nets that would not stretch under heavy loads. The Oregon flax growers and processors responded by producing a fiber for these specialty articles that stood the most exacting tests.

Aware of the acute fiber shortage, our government encouraged the production of flax in Peru and other countries in the early years of World War II and urged still greater production in Oregon. In 1942 four modern flax-processing mills were constructed, and finally in 1943, through the financial assistance of the Defense Plant Corporation, two additional mills were built. All processing mills are located in the Willamette Valley and represent an industry which is now valued at $3,000,000. At 1948 prices a cash outlay of approximately $225,000 is required to construct and equip a flax mill capable of handling 2,000 tons of flax straw annually.

Oregon produces 98 per cent of the total fiber flax grown in the United States, which is a very small part of the total world output. Russia, Poland and the Baltic countries account for 85 to 90 per cent of the world's production. Contrary to common belief, Ireland grows and processes only a small part of the fiber used in the material manufactured there, being dependent on continental Europe for 90 per cent of her raw fiber consumption. Oregon and Washington have every necessary natural facility for raising the crop, and there are over 500,000 acres suitable for flax production in Oregon alone.

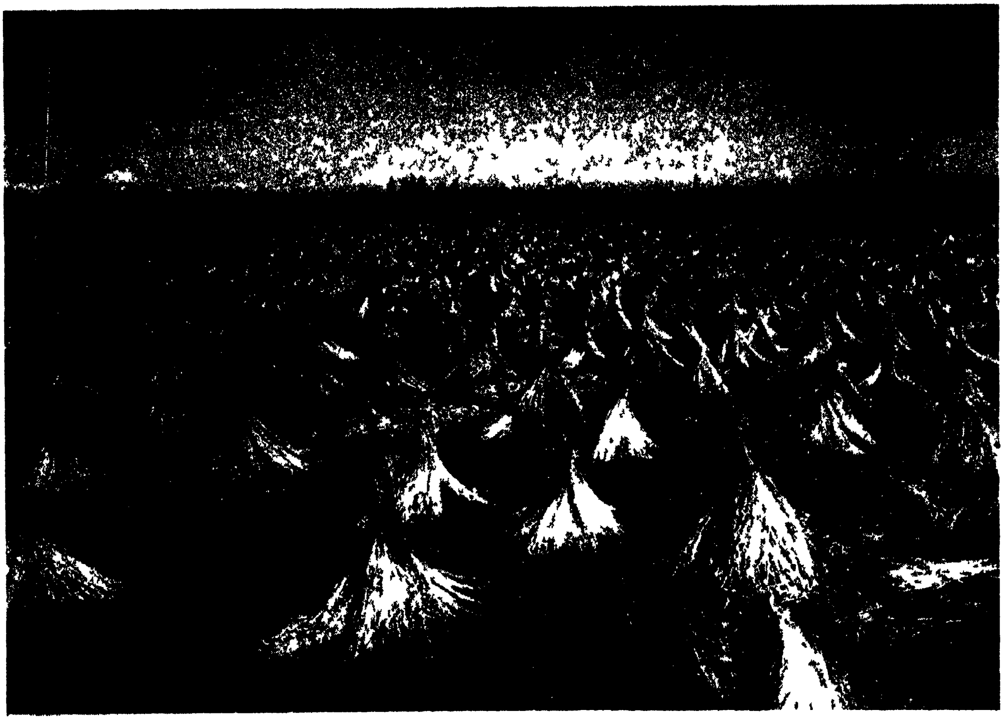
Growing Flax

The growing and processing of fiber flax entail several operations which are fundamentally the same today as they were 5,000 years ago. It is commonly thought among Europeans that the ability to produce and process flax is hereditary. Certainly heredity played no part in the development and expansion of the Oregon industry during the past decade. Fortunately agronomic experiments had been conducted at the Oregon Agricultural Experiment Station for many years previous to the industry's war-time expansion. Consequently Oregon farmers, who are good cooperators with the State Extension Service, soon learned of the more important phases of flax production. They are careful to plant their flax early in March and not later than mid-April. During this period Oregon experiences a cool moist climate which is most beneficial for both quality and quantity production of fiber flax. If planted later during the dry warm season, the flax is usually stunted, and often a harsh fiber of poor spinning quality results.

The producer strives to select a fertile well-drained soil which is free of noxious weeds. Weeds are especially undesirable because they are difficult to remove from the fiber. Through the advance of control by selective sprays the farmer is now able to destroy many of the heretofore troublesome weeds and at the same time to avoid injury to the tender flax plant. Spraying, if necessary, takes place when the flax is three to four inches tall. When the spray is applied properly, the weeds which are more susceptible to the chemicals die and the more resistant flax plants continue to live. The crop usually reaches its maximum growth about June 15, at which time the pretty blue and white flowers appear. The plant often reaches a height of 40 inches. Yields vary from one to four tons of cured unthreshed flax per acre. Each flower accounts for one boll which may contain as many as ten small brown seeds. When about half the seeds are ripe the grower is aware that it is time to harvest. Harvesting normally occurs about July 15.

Harvesting

The crop is harvested by an especially designed machine which pulls the entire plant up by the roots. The reason for pulling and not cutting is to harvest all the fiber which extends through the stem into the root. Long fibers are most desirable in the spinning operation. The pullers are equipped with binding attachments which tie the flax plants into bundles of suitable size. Flax-pulling machines were first introduced into foreign countries, but the ingenuity of the American engineer has resulted in new developments and designs which have simplified flax harvesting and which have entirely eliminated the laborious hand pulling operation in Oregon. In



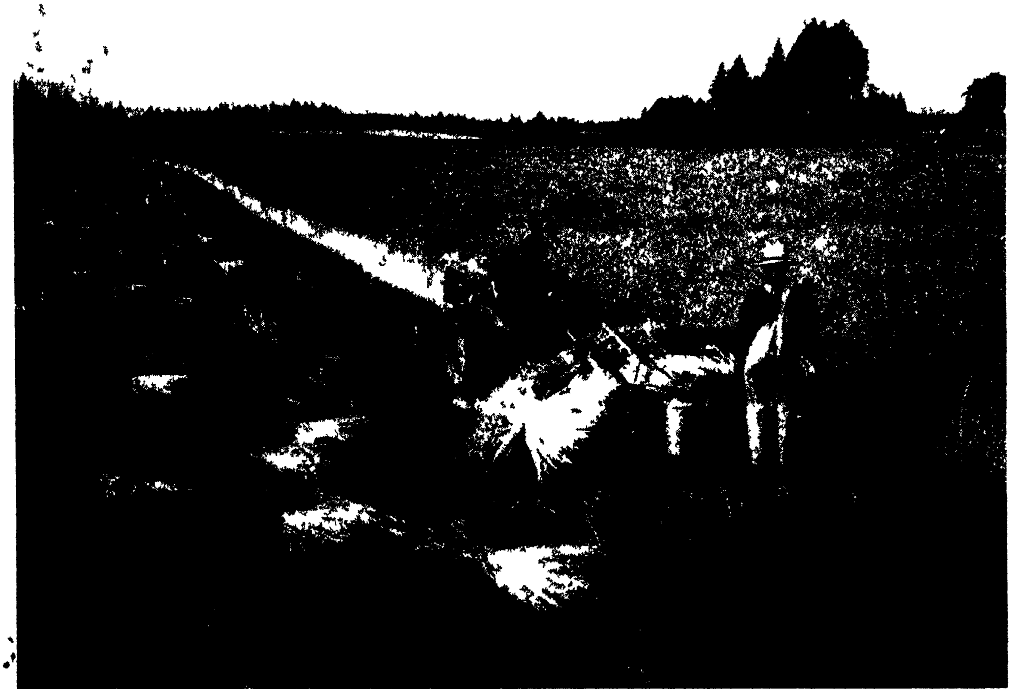


FIG. 1 (*Upper*). Drying flax straw by stacking each harvested bundle separately in wigwam fashion.

FIG. 2 (*Lower*). Machine pulling and binding of flax in the Willamette Valley, Oregon.

many flax-growing areas in Europe, rain at harvest time often damages the crop. Oregon, however, is usually fortunate in having favorable weather during this period.

Flax must be harvested at the proper time in order to obtain a strong fiber. Harvesting when overripe results in an inferior product. After pulling, the bundles are placed in shocks to cure and dry. The farmer then loads the bundles and delivers them to the processing mill. Hauling large loads enables him to minimize the cost per ton, but he is looking forward to the time when less hand labor will be required for this laborious operation. After unloading the bundles in one of the large storage sheds at the processing mill, the farmer's work with the crop is finished. The responsibility of converting the flax into spinnable fiber rests with the mill operator.

Processing

Deseeding. The first phase in the processing of flax at the mill is deseeding. Because of the rapidity with which the flax is delivered to the mill, it is necessary to store most of it before deseeding. Especially built machines remove the seeds without tangling or damaging the stems. The bands of the bundles are cut and spread so that a thin layer of plants is passed through the deseeding machine. Common types have a revolving comb that removes the seed bolls without breaking the stems. The seed is then separated from the bolls by a stationary cleaner. When the seed and bolls have been removed the stems are left in a straight untangled condition and are re-tied into bundles and held by two separate bands to prevent tangling and to facilitate handling in the next operation—retting.

Retting. Retting means "rotting." Two layers of deseeded flax bundles are placed in an upright position in large concrete vats. After the vat has been filled with straw a timber grid is locked over the bundles to prevent them from floating when the water enters the tank. Ordinary water without addition of chemicals is suitable for retting. The water is heated by steam to a temperature of 85 to 90 degrees Fahrenheit, which is optimum for the growth of retting organisms, and this temperature is maintained throughout the ret. Bacteria which are naturally present on the straw cause the encrusting substances to deteriorate, thereby loosening and separating the individaual fiber bundles from the inner woody portion of the straw. Retting is merely another example of the decomposition of vegetable organic matter by micro-organisms. The retting period usually lasts from four to eight days, depending on the type of straw and the temperature maintained. The straw is examined periodically while the ret is in progress to determine the exact time to drain the retting liquor and stop the retting action. If the straw remains in the water for too long a period it becomes over-retted. This means that the fiber bundles may break down into ultimate fiber cells and the commercial strands of fiber cells will be weakened. When this happens, strength, one of the finest qualities of linen, is destroyed. On the other hand, if the ret is stopped prematurely, it will be difficult to remove the inner woody core of the stems from the fiber because of the adhesive nature of the remaining incrustant materials. Stopping the ret at the proper time is very important and requires both skill and experience. The person in charge of retting can usually determine the so-called end point of the ret by making physical examination of the straw to note the ease with which the fiber slips off the woody core, and by closely observing the appearance of the individual fibers as they separate.

FIG. 3 (*Upper*). Finished flax fiber (left) and incoming flax.
FIG. 4 (*Lower*). Delivering dry flax straw to a processing mill.

When the ret is judged completed, the retting liquor is drained and fresh cold water is allowed to enter the tank to rinse impurities from the straw and to stop the retting action. The rinse water is then drained and the bundles allowed to dry for a period of ten or twelve hours in order to facilitate the handling of the wet straw. The wet soggy bundles as removed from the tanks are loaded on trucks or wagons and moved to a drying field where they are individually set up in wigwam fashion for faster drying. The climate in Oregon is favorable for drying only during the summer months, which is the reason why the retting is during this period.

When the straw has been thoroughly dried, it is re-tied and placed in storage until winter, when it is scutched. There has been very little artificial drying of flax straw in Oregon. The practical experienced flax man believes it is possible to dry artificially and not destroy any of the inherent good qualities of the fiber. Natural drying is the method commonly practiced in Europe where hand labor is more abundant than in

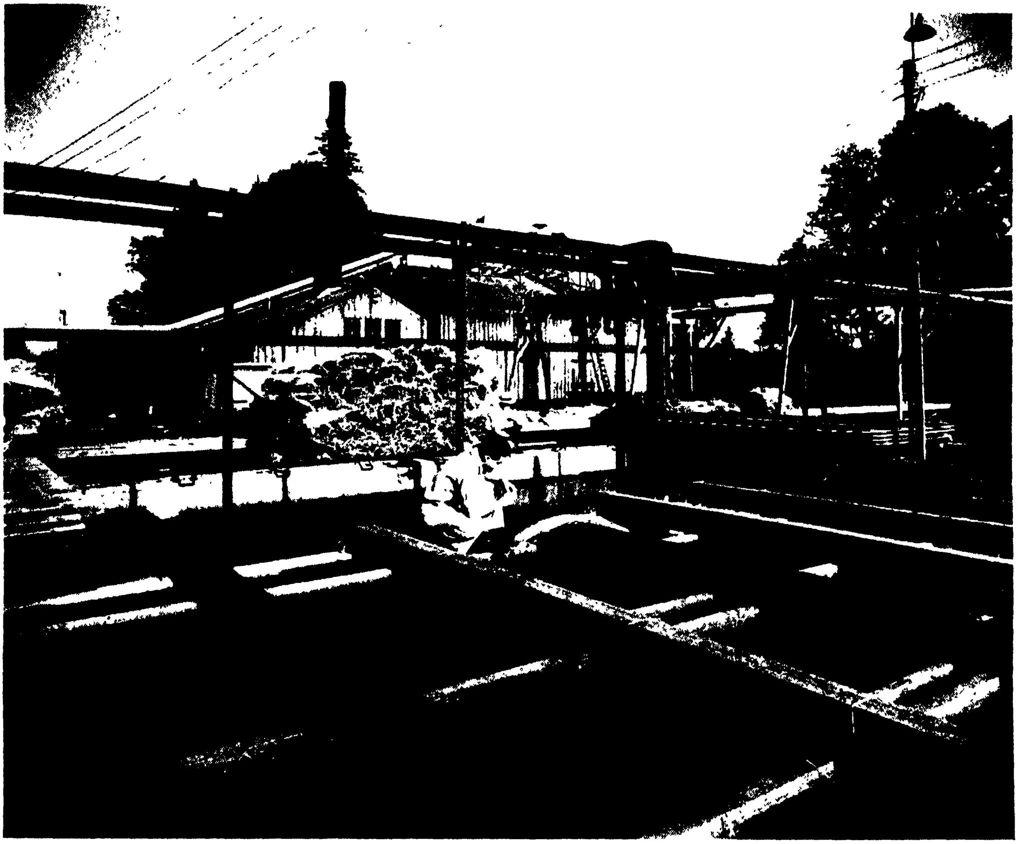
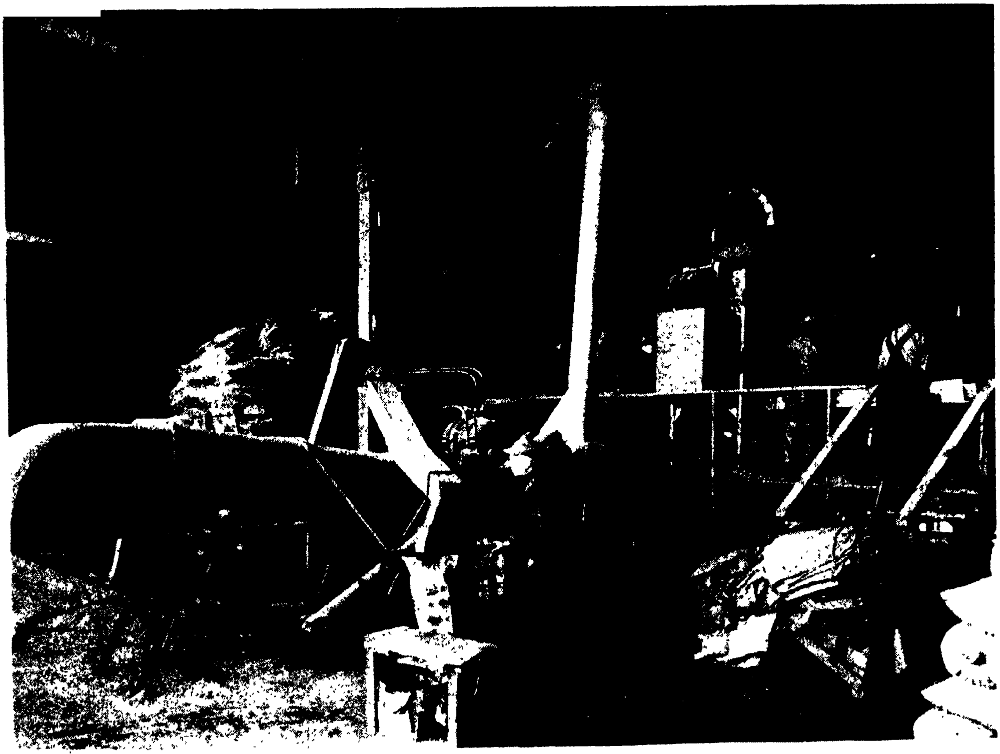


FIG. 5. Retting tanks, in which the flax fiber is separated from the other tissues of the straw by bacterial action. This process must be carefully controlled, and the man pictured is testing the straw by breaking it to determine whether the "end point" has been reached, that is, the point where the surrounding tissues have rotted sufficiently to permit other processing in the mill but where the fibers themselves have not yet been attacked.



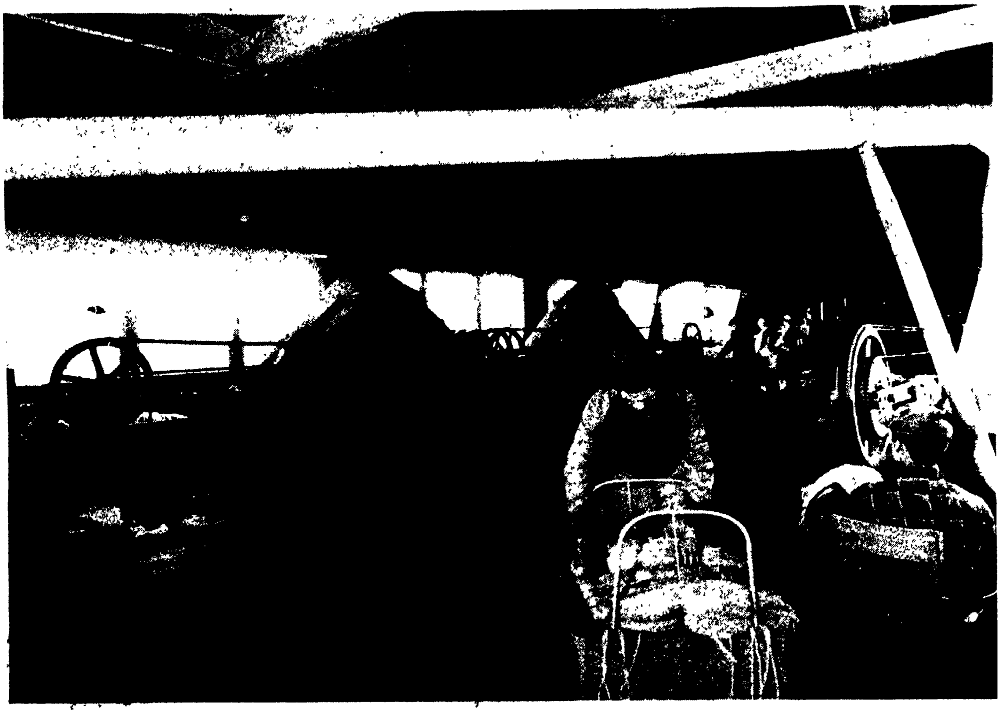


FIG. 6 (*Upper*). Deseeding, the first operation at the processing mill, before retting.

FIG. 7 (*Lower*). Scutching, the third operation, by which the woody material of the straw is broken away from the fibers. This operation is facilitated by the previous retting.

the United States. Artificial drying, where practiced in Europe, eliminates the seasonal operation of flax processing by permitting the retting operation to continue throughout the year. This may mean lower production costs and it does result in a more rapid turnover of the capital invested. Persons interested in the flax industry are looking forward to the development and commercial adaptation of a successful artificial drier.

Scutching. This operation, which is the process by which the woody material of the straw is broken away from the fibers, is usually carried on in Oregon during the rainy winter months. During this period the straw has a higher moisture content, which adds flexibility to the fiber so that there is less breakage and loss of long fibers in scutching. In the scutching operation, the bundles of stems are opened and spread into a "rug" or "mat" which feeds into a gripping device. This device holds the straw securely while it passes through a series of fluted rollers which break the woody core into small sections called "shives." The broken flax, while held in the same gripping device, passes through a long drum containing rotating blades which scrape and beat the shives out from the fiber. Workmen collect the fiber, now known as "line fiber", as it reaches the discharge end of the machine into small bundles known as "hanks". The shives are blown into a storage room where they are kept until the next retting season when they are used as fuel to heat the retting water. Short broken lengths of fiber or tangled fibers which may have been pulled from the gripping device by the action of the beaters are called "tow". It is collected at the bottom of the scutcher and fed directly into a tow-cleaning unit which removes adhering shives and other foreign material. Oregon line fiber is suitable for use in manufacturing linens, high-grade yarns and cordage. Tow is used in less expensive linens and in lower-grade yarns. It is also used in the manufacture of "flax" rugs.

Hackling. The last operation at the processing mill is hand hackling. This consists of pulling the hanks of line fiber over a set of sharp steel pins in order to remove any remaining foreign material,

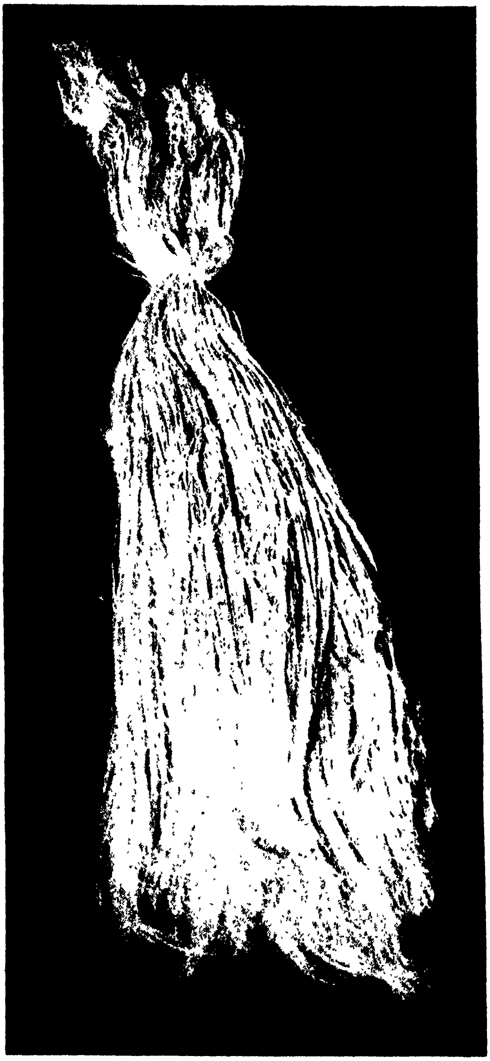


FIG. 8. Line fiber as it comes from the scutching machine.

short lengths of fiber, and to remove any entanglements. It partly subdivides the fiber strands, but fine hackling is performed in a spinning mill. The hand hackling results in a more uniform and attractive appearing commodity. The short fiber lengths removed in hackling are called "pullings" in Oregon. The long line fiber is graded and then neatly baled for shipping to the spinner. Since there are only two flax-line spinning mills in Oregon, it is necessary to ship most of the fiber to Eastern mills. The following table gives the approximate percentage yield of various flax products, based on the pulled, cured, unthreshed flax delivered by farmers:

Product	Percentage
Dressed scutched fiber	7.0
Pullings fiber	.5
Tow fiber	5.0
Seed	17.0
Chaff—bolls	15.5
Shives	41.0
Retting loss	14.0
Total	100.0

Economics

The Oregon fiber flax industry expanded during the last war and is now forced to compete with foreign producers. During the Nazi occupation, a large amount of fiber was hoarded in western Europe, some of which was later sold in the United States to obtain much needed American dollars. The release of this large stockpile of European fiber had an adverse effect on the price of Oregon fiber immediately following the war. The increasing cost of processing coupled with foreign competition has forced three of the Oregon processing mills out of business and three others to close temporarily.

The adverse effects of the sudden sale of surplus European flax fiber at the close of the war were alleviated to some extent by a federal price support program for all fiber flax produced in Oregon prior to 1947. The purpose of this assistance was to help the processors become adjusted to peace time production. Additional federal support has been sought in order to allow the industry time to further adjust itself to foreign competition.

The remaining seven mills are determined to continue operating if at all possible. They propose to do this by improving the quality of their fiber and by further mechanizing their operations. They are cognizant of the fact that many American industries would not be in existence today if obsolete hand processing methods had not been eliminated. The Oregon flax processor is appreciative of the research program conducted in Oregon by the United States Department of Agriculture in cooperation with the Oregon Agricultural Experiment Station. A new and superior fiber variety named "Cascade", released in 1945 by the Department of Agriculture, has given most encouraging results at home and abroad. Research in the mechanization of processing initiated in 1938 at the Oregon State Agricultural Experiment Station has aided the industry in reducing processing costs. It is not unreasonable to expect the development of more efficient labor-saving machines that will benefit the infant industry. Hand-labor operations are so numerous in the flax industry that it might properly be termed "a research engineer's paradise".

The Oregon flax producer is hopeful that a spinning and weaving mill will be established on the West Coast which would consume a larger part of his production.

Progress in the establishment of grades for Oregon flax fiber is being made, and it may soon be possible for spinners to buy fiber by grades denoting greater use value. This is of major importance in the development of better markets. The sale of Oregon fiber has always been handicapped by an inadequate grading system established when the industry was very young. The grading method placed emphasis on length, and no significance was attached to fiber strength, fineness and spinning properties. Spinners recognize Oregon fiber for its inherent qualities but dislike the Oregon grading system, since they are

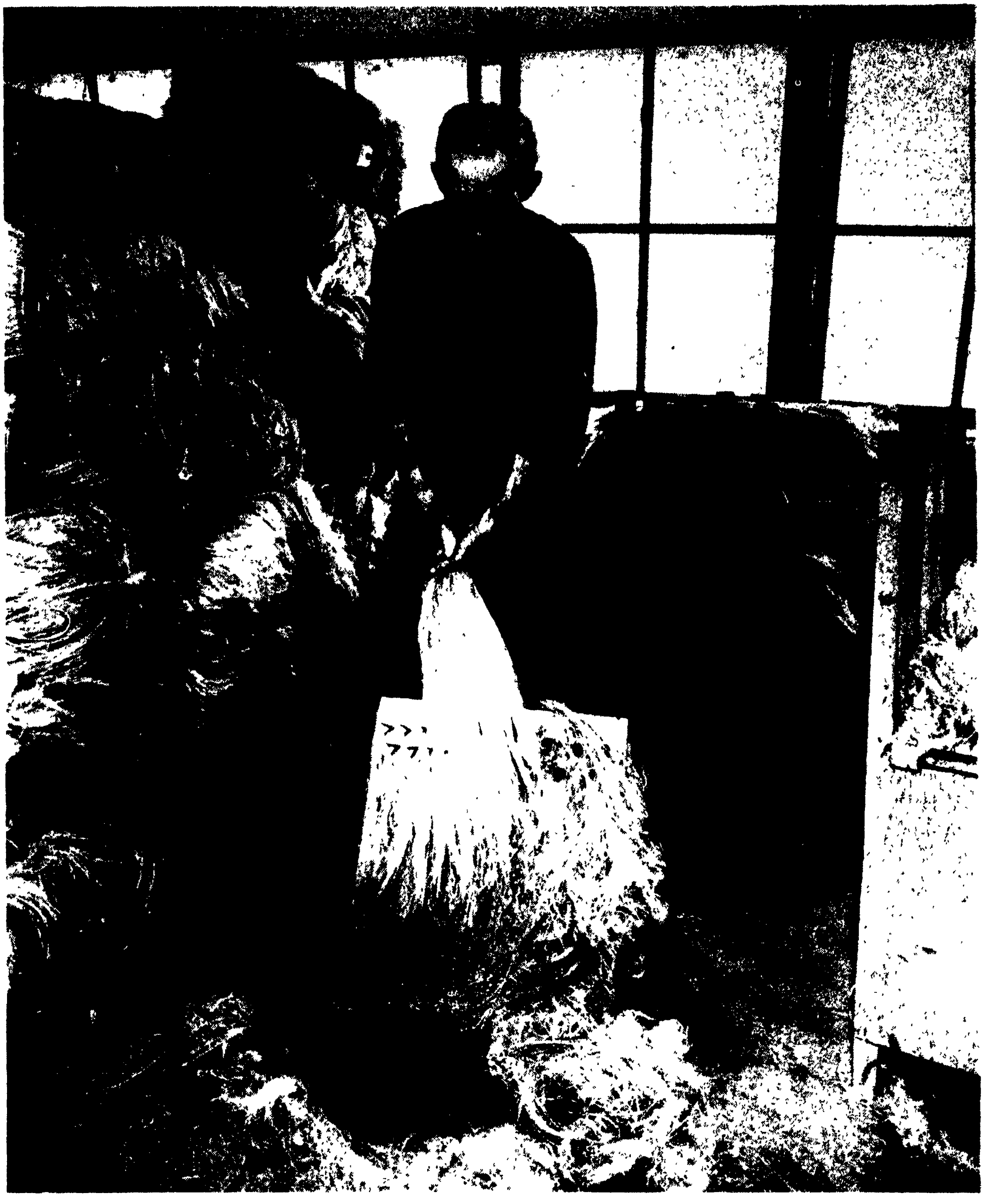


FIG. 9. Hand-hackling, the last operation at the processing mill, by which hanks of line fiber are pulled over sets of sharp steel pins in order to remove any foreign material and short lengths of fiber, and to straighten the fibers.

compelled to sort the fiber within the various lengths in order to obtain the particular types suited to their needs. Often they have had to resell types for which they had no use. During the war when the demand for fiber was so great, a seller's market existed and efforts to establish grade standards for Oregon fiber were of little interest. The industry is now feeling the bad effects of the poor standards created during the war.

Since fiber flax is a non-surplus crop it is particularly valuable to Oregon farmers and fits well into the rotation ~~of their agricultural program.~~

Each processing mill has an annual payroll of approximately $80,000 which benefits the farming communities in which they are located. Many people feel that this genuine rural industry should be preserved, not only because it is important to our national economy but also because it might again be useful in the event of another emergency.

Possessing a background of "know how" and with the greatest confidence in progress through research, the Oregon flax processors are determined to supply an elite fiber for the manufacture of domestic linen products.

Utilization Abstracts

Carob. The carob (*Ceratonia Siliqua*) is an evergreen tree native to the eastern shores of the Mediterranean where for centuries its pods have been an important form of animal feed. Sicily, Cyprus, Malta, Crete, the southern half of Sardinia and the Adriatic coast of Italy in the vicinity of Bari have been the chief producing regions, and from 1901 through 1930 an annual average of nearly 44,500 tons, valued at about $920,000 were exported from the Island of Cyprus alone. In 1854 this species was introduced into the United States by the U. S. Patent Office, and in 1859 some 8,000 plants were distributed. For many years the carob has been in very common use as an evergreen shade tree bordering streets and boulevards in all California towns where frost is not too severe, and many fine specimens are to be seen.

The planting of this tree on semi-arid areas in the West, as a means of erosion control and land reclamation, especially where irrigation for other crops is impractical, is now being urged by Dr. Walter Rittenhouse of San Diego, California, who has provided funds for a small demonstration carob orchard to be managed in cooperation with the University of California and the Soil Conservation Service.

While any commercial plantings of carob in California should be based on soil conservation and domestic animal food, there are many other uses which, if properly promoted, may result in additional and perhaps substantial values. Various food products have been manufactured on a small scale in California from imported carob pods, including carob flour, carob syrup and a breakfast food. In addition, the seeds can be developed as a source of manogalactan gum which is now being manufactured in Europe from Mediterranean grown seeds and used in ice cream, salad dressings, pie fillings, French dressings, cosmetics, pharmaceuticals, detergents, matches, water emulsion paints, inks, shoe polish, insecticides and mucilage. (J. E. Coit, *Carob Culture in the Semi-arid Southwest. 15 pp. Rittenhouse, San Diego, 1949.*)

Papaya. *Carica monoica,* a close relative of the papaya (*C. papaya*), differs from the latter in producing a fruit that is inedible when fresh but which resembles stewed peaches or apricots when cooked with sugar and a little lemon or lime. In Peru, where it is native, it is known as "col de montana" and as "papayeta", and its leaves are highly prized as a vegetable but used in this capacity apparently only very locally. It has been recommended as a promising new fruit and vegetable for the United States Corn Belt. (C. F. Swingle, *Proc. Am. Soc. Hort. Sci. 49: 137. 1947.*)

The Essential Oil of Pectis Papposa

This oil, produced by a heavily scented herbaceous plant of the American Southwest and northern Mexico, is rich in cumaldehyde and carvone, and is therefore a potential commercial source of these fragrant aldehydes, now obtained from cumin, caraway and dill seed oils and used in flavoring food and beverages.

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California Institute of Technology

General Characteristics of the Plant

The genus *Pectis* was founded in 1758 by Linnaeus to embrace two West Indies species (3). Approximately 50 species of the genus are native to North America, twelve of them common to the southwestern States. They are, in general, rather low branching, mostly heavily scented herbs, distributed from New Mexico to Sonora at altitudes varying from sea level to 4,000 feet in a range similar to that of *Larrea tridentata*, the creosote bush.

Pectis papposa Gray, commonly known as chinchweed, is an attractive plant up to ten inches in height with bright yellow flowers and dark green foliage. When crushed the leaves give off a pleasant fragrance, and where growth is extensive its perfume is noticeable for considerable distances. Because of this pronounced fragrance the species *papposa* and *angustifolia* were used by the Indians of the Southwest for flavoring their foods and by the Indian women as a perfume. They also obtained dye from the plant.

The oil glands of *P. papposa* are located at the margin of the leaves and can be readily seen with the naked eye. When the gland walls are broken the leaf assumes a serrated effect on the margin, hence the name *Pectis* (Greek to comb). It is interesting to note that as soon as the two cotyledons appear on germination of the seed, they are equipped with these tiny oil glands.

Seed is produced very abundantly in the form of pointed rods approximately 5.0 mm in length by 0.5 mm in width. On maturing the plant deposits a carpet of seed on the ground ready to germinate when sufficient moisture is present and minimum night temperatures are around 70 degrees F. It flourishes with maximum temperatures as high as 120 degrees F., maturing under favorable conditions in four to six weeks.

The fresh seed has low germinating power but after storage for a few months germinates very well. Our experiments indicate that the oil secreted by the plant has an inhibiting effect on germination.

Pectis papposa is equipped with a strong tap root and laterals for utilizing any moisture available in times of stress. In common with most desert plants, its mineral content is high, the ash running around 10% of the dried plant.

The essential oil content of two species of *Pectis* have been reported in recent literature. Fresh plants of *P. Texana* (1) yielded 0.72% oil, 48% of which was thymol. Similar plants of *P. elongata* (2) gave 0.216% of oil which was 60% citral. As will be noted, the three species, *Texana, elongata* and *papposa,* yield oils of widely different compositions.

Experimental

Collection and Distillation. The plants of *Pectis papposa* from which the oil for this study was obtained were collected in Coachella Valley, California, and South Gila Valley, Arizona. Fields of raw desert sand which had been wetted by rain or irrigated supplied an excellent crop of the plant, quarter acre patches yielding at the rate of approximately three tons per acre green weight. Several collections were made over a period of two years, totaling about 300 pounds of green plant. The date, location and yield of oil of the various samples are shown in Table I.

It will be noted that the percentage of oil in samples I and II is considerably higher than that of V and VI, though the moisture content and conditions of growth are similar. This is due to the different methods employed in handling the plants preparatory to distillation. Numbers I and II were distilled in the field immediately after collection, approximating commercial methods and avoiding loss of oil by volatilization during transportation to the still. Samples V and VI were transported in bags by car about 150 miles when temperatures in some cases were around 100 degrees F. and with distillation necessarily delayed. Sample IV was collected when the plants had been mature for some time and had lost a portion of their leaves. It is obviously not a normal sample and was characterized by a low yield of oil with a sharper odor in contrast with the oil from other collections.

A ten-gallon tin-lined still with steam inlet under a false bottom and connected with a glass condenser was used for recovering the oil from the plant. In a current of live steam, around two hours were required to exhaust a ten- to twelve-pound sample. The lush plants yielded a pale yellow oil. That from over-mature material was a little darker. The oil tends to darken on exposure to light and was therefore stored in a dark cool place previous to fractionation.

Fractionation. The results obtained by fractionating the oils from samples I, II, III, V and VI and the constants obtained on analysis of these fractions are recorded in Table II. These are averages of results from individual fractionations of the different collections, the constants of the corresponding fractions not showing much variation. A Cenco high vacuum pump was used for the high boiling fractions.

Terpenes. Fraction I, Table II, has

TABLE I

Sample number	I	II	III	IV	V	VI
Date collected	June 1947	June 1947	October 1947	Dec. 1947	July 1948	Aug. 1948
Location	S. Gila Arizona	Coachella	Coachella	Coachella	Coachella	Coachella
Moisture %	68.	75.	60.	20.	72.	74.
Oil % by wt. green plant	0.60	0.44	0.45	0.40	0.35	0.35
Oil % by wt. dry plant	1.87	1.76	1.12	0.50	0.90	1.00

a characteristic terpene odor, and its constants closely approach those of beta pinene. The optical rotation, however, is dextro, while that of beta pinene is ordinarily laevo. There are, however, a few exceptions to this rule (6).

A portion of fraction I was purified with Girard reagent (9), dried over metallic sodium and distilled at atmosphere. This purified terpene had an optical rotation of minus 6.9°, showing that impurities were responsible for the positive rotation. On redistillation, a small amount, about 2% of the purified terpene, came over at 156° C, indicating presence of alpha pinene. Approximately 50% of the terpene distilled at 168°–169° C, and the remainder at 171°–172° C. The odor of these fractions was characteristic of beta pinene. The physical constants of the 168°–169° C b.p. fraction were as follows: density 0.863, refractive index 1.4720, specific rotation –6.7°.

A portion of the terpene was oxidized with alkaline potassium permanganate (8), the sodium salt obtained acidified with dilute HCl and the solution extracted with ether. On drying the ether solution, characteristic long needle-shape crystals of nopinic acid were obtained, m.p. 126°–127° C. These did not depress the m.p. of pure nopinic acid, and the presence of beta pinene was thus established in the *Pectis* oil.

Carene. The constants of Δ^3 carene lie close to those of beta pinene. The nitrosate test made on a portion of the purified terpene gave negative results, however, indicating absence of Δ^3 carene.

Benzaldehyde. Qualitative tests on the terpene fraction I showed that an alcohol solution of 2–4 dinitrophenylhydrazine gave a yellowish crystalline precipitate. The recrystallized precipitate had a m.p. of 235°–236° C. In order to identify the unknown material in this fraction, the water phase of the Girard reagent obtained in the purification of the terpene was acidified with HCl, extracted with ether, the ether washed with Na_2CO_3, water, and distilled under diminished pressure. A brownish oily residue was obtained

TABLE II

PHYSICAL CONSTANTS AND CHARACTERISTICS OF PECTIS OIL AND ITS FRACTIONS

Fraction	*Grams*	*Color*	*Odor*	*Density* $d\frac{25}{4}$	*Index refraction* $\eta\frac{25}{D}$	*Distillation range*		*Specific rotation* $[\alpha]\frac{25}{D}$	*C %*	*H %*	*Active H*
						b.p. deg. C	*press mm.*				
Original Oil	100.0	pale yellow	cumald.	0.930	1.4992	....		+16.3	....	.. ..	. ...
I	31.0	clear	terp.	0.864	1.4748	68°–71°	20.	+8.5	86.25	11.30	0.0
II	30.0	pale yellow	cumald.	0.972	1.5167	65°–70°	0.1	+12.0	80.50	8.88	0.0
III	28.5	yellow	cumald.	0.973	1.5187	72°–77°	0.1	+11.7	80.31	9.55	0.0
IV	2.5	reddish	sharp cumald.	0.970	1.5190	88°–100°	0.1		80.77	10.07	.. ..
Residue	8.0	red	aromatic								
Total	100.0										

which had the characteristic odor of benzaldehyde. The m.p. of benzaldehyde 2–4 dinitrophenylhydrazone is 235°–237° C, agreeing with that of the hydrazone obtained from the terpene fraction I. This hydrazone did not depress the m.p. of the benzaldehyde 2–4 dinitrophenylhydrazone but did depress the m.p. of the corresponding cumaldehyde compound quite markedly. These tests indicate that benzaldehyde is present in *Pectis* oil to approximately 1%.

Cumaldehyde. The odor of the original oil and of fractions II and III, Table II, is characteristic of cumaldehyde. The other physical properties of these fractions, however, do not correspond to those for pure cumaldehyde, the density and refractive index being lower and the optical rotation plus 12 degrees, while cumaldehyde is inactive. Furthermore, the 2-4 dinitrophenylhydrazones of these fractions depress the m.p. of pure cumaldehyde 2–4 dinitrophenylhydrazone.

A saturated water solution of sodium bisulfite, $NaHSO_3$, gives a heavy precipitate with these fractions (5). Making this precipitate alkaline with NaOH, and steam distilling, yields a colorless oil having physical constants as follows: density 0.974 and a 2–4 dinitrophenylhydrazone with m.p. 243° C from alcohol solution. This did not depress the m.p. of cumaldehyde 2–4 dinitrophenylhydrazone.

When fractions II and III are shaken with a saturated water solution of normal sodium sulfite, Na_2SO_3, 20% of the oil goes into solution, leaving 80% unreacted. Redistilling this residual oil yields a colorless oil with physical constants: density 0.973^{25}, refractive index 1.5270^{25}. Constants for cumaldehyde are: density 0.973^{25}, refractive index 1.5280^{25}.

A portion of fraction III was moistened with a 30% solution of hydrogen peroxide and exposed to the air for several days. Characteristic crystals of cuminic acid developed, m.p. 117° C. These results identify the presence of cumaldehyde in *Pectis* oil in amounts equivalent to 46.8% of the original oil.

Carvone. As has been noted, the high boiling *Pectis* oil fractions react with a saturated water solution of normal sodium sulfite, 20 per cent of the oil going into the water phase and 80 per cent remaining unreacted. Cumaldehyde was identified in this residual oil.

By making the Na_2SO_3 solution of the ketone alkaline with NaOH and distilling with steam, a small quantity of a pale greenish yellow oil was obtained. It is established that the ketone is not recoverable quantitatively from this solution. This oil had the characteristic odor of carvone. Its refractive index was 1.5020^{25}. The refractive index of carvone is 1.4980^{25}. A 2–4 dinitrophenylhydrazone was obtained from this oil having an m.p. of 190°, the same as that of the carvone hydrazone. The mixed m.p. did not depress the m.p. of the carvone hydrazone, thus identifying the presence of carvone in *Pectis* oil to the amount of 20% on the high boiling fractions equivalent to 11.7% of the original oil, based on the absorption test with the normal sulfite solution.

In the reaction of the ketone with the normal sufite, alkali is released. Experiments have shown that the amount of alkali released, as measured by a standard acid, can be used in estimating the amount of aldehyde or ketone present (7). The presence of cumaldehyde in this fraction having already been established, an experiment was carried out on a known mixture of two thirds cumaldehyde and one third carvone, determining the amount of standard acid required to neutralize the alkali liberated. The experiment was conducted at room temperature, using phenolphthalein as an indicator and allowing to stand over night. The unreacted oil was recovered with ether and amounted to 92% of the cumaldehyde taken. The reaction with cumaldehyde is thus shown to be very slow, while carvone reacts quite rapidly.

Sadtler (7) has shown that two molecules of carvone liberate alkali equivalent to one molecule of HCl. On this basis the acid required to neutralize the alkali liberated by the *Pectis* oil ketone was found to be equivalent to 18% of carvone in the high boiling fraction. This approximates the amount, 20%, of the ketone found by direct absorption.

A further check on the composition of fractions II and III was made by comparing the theoretical density, refractive index and optical rotation calculated on the basis of 80% cumaldehyde and 20% carvone with those constants found by analysis as follows:

Density	calc.	0.971^{25}
	found	0.971^{25}
Refractive index	calc.	1.5217^{25}
	found	1.5187^{25}
Optical rotation	calc.	12.6°
	found	12.0°

Identification of carvone in the presence of cumaldehyde by the hydrogen sulfide method of Wallach (4) was unsuccessful, since cumaldehyde also reacts with H_2S in an alkaline medium giving an amorphous bulky precipitate unlike the crystalline product obtained from carvone.

Chromatographic Identification. In order to determine whether the 2–4 dinitrophenylhydrazones of the original *Pectis* oil could be separated and identified chromatographically, a solution of these hydrazones in a mixture of benzene and ligroin was absorbed on a column of silicic acid and "Cellite". Zones having the m.p. of cumaldehyde and carvone dinitrophenylhydrazones were obtained, but the benzaldehyde zone did not develop, probably because of its low concentration in the mixture.

Pectis Seed and Production

Like cumin seed condiment, *Pectis* seed imparts the spicy flavor of cumaldehyde, due to the presence of this oil in the fruit. The seed of *P. papposa* is much smaller than that of cumin but is produced in large quantities. Weight measurements indicate that a good crop of *Pectis* would yield up to 150 pounds of seed per acre.

Experiments are being made on growing *Pectis papposa* in the South Gila Valley, Arizona. No difficulty has been experienced in germinating the seed, but control of weeds is a problem in cultivated fields, and *Pectis* is not very weed-resistant. If a satisfactory crop could be produced, yielding 25 pounds oil per acre, the crop could be harvested and the oil recovered by methods established for harvesting peppermint, with a minimum amount of hand labor. The oil would probably be evaluated on its cumaldehyde and carvone content and applied where they are utilized.

Resumé

Pectis papposa is found native over large areas of the Southwest, yielding in some cases, based on quarter acre pieces, at the rate of three tons green weight per acre. Yields of 0.40% to 0.60% of oil on the green plant basis have been obtained by steam distillation.

Constituents identified in the oil and

their approximate percentages are the following:

	%
Beta pinene	27.0
Alpha pinene	2.0
Cumaldehyde	47.0
Benzaldehyde	1.0
Carvone	12.0
Esters	Small amount
Acids	Small amount
Alcohols	None

The percentage of cumaldehyde in *Pectis* oil is approximately the same as in cumin oil, and *Pectis* oil and caraway are unique in containing both cumaldehyde and carvone.

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Utilization Abstract

Rice Hulls. Texas is now the nation's largest rice-growing State, with an annual crop of some 24 million bushels. The rice hulls from this State together with those from mills in Arkansas, Louisiana and California amount to about 300,000 tons annually, and their utilization has long been a problem; most of them have heretofore been burned near the mills for want of a better way to dispose of them. Now, however, "furfural, acetone, glue-spreader, abrasives, extenders of plastics, art panels, wallboard, insulation materials, an ingredient of grime-removing soaps, filler for cement and other composition building blocks, sweeping compounds, an edible oil from rice bran and several other chemical materials are beginning to attract the interest of processors as well as growers of rice".

While some progress has been made in using Texas rice hulls as an ingredient of cement building blocks, all the other phases of utilization are still in the experimental stage, and the Western Regional Research Laboratory in Albany, California, is pursuing work in this direction.

Rice bran contains about 20% oil which has not yet found an outlet, while the bran itself and rice polish find ready markets ranging at times from $40 to $80 per ton. It is the hulls which so far have little outlet, though they have been used successfully by the Quaker Oats Company at Memphis, Tennessee, as a source of furfural. Oat hulls have long been the principal source of this chemical, and more recently cottonseed hulls have been utilized for the same purpose. (*From Texas Chemurgic News, as condensed in Chemurgic Digest, 8(2): 12. 1949*).

Problems Associated With the Procurement of Plant Products From the American Tropics

Industrial utilization of the vast wild vegetable resources of Latin America involves much more than the solution of technological problems. More difficult, at times, are the problems of labor, politics, transportation, native apathy and climate.

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Introduction

It was impressed quite abruptly upon some of us engaged in procurement of vital materials from the American tropics during the recent war, how inexperienced and even naive were some of the United States' foremost business leaders when it came to dealing with tropical products and Latin peoples. To a man behind a desk in Washington, accustomed to procuring standard items in standardized temperate zone markets, it well might seem that increased procurement and production are directly geared to dependable offering price. In the United States a purchase offer well in excess of standard market prices would normally be sufficient to stimulate flow to the would-be purchaser, and the producer would find ways and means to facilitate and increase production, perhaps at the expense of other products, simply because it would thus become the most profitable thing to do. In the tropics, however, various complicating factors seldom permit such a simple cause-and-effect relationship, and in extreme cases rise of price beyond a certain optimum may actually depress production. In the subsequent paragraphs some of the many factors that must be weighed in initiating procurement of wild vegetable products from the American tropics are briefly discussed.

Transportation

One of the most serious difficulties to be overcome in exploiting wild tropical American plants is the inadequacy of transportation. Extensive stands of almost any economically important wild plant, with the exception of coconut, mangrove and a few others, are today distant from formalized lanes of transportation, often remote in the hinterland where no dependable transportation whatsoever is available. Most striking in this respect are the vast interior of Brazil and the Andean countries on their eastern slopes. Areas of small extent, such as Darien province of Panama, Peten district of Guatemala, the interior of Honduras, and, in fact, the whole central mountain core of Central America, also present formidable obstacles. Each of these localities, abounding in plants useful to man, are many days, or even weeks distant in both time and effort from marketing or manufacturing centers, and in the immense interior of South America remote in mileage as well.

Through much of tropical America occur geographical and climatic barriers more severe than those typical of temperate North America, with either or both incentive and means for surmounting these barriers lacking. Coastal areas are frequently bordered by treacherous bogs and impenetrable mangrove tidal swamps, with shallows and offshore bars further hindering access from the sea. Inland occur terrains more adaptable to ordinary transportation, but on the Caribbean slopes of Central America and the north shore of South America heavy rain and encroaching jungle make establishment and maintenance difficult and expensive. In northeastern and eastern South America shifting sand, seasonal rains and semiarid climate limiting the population make economical upkeep of hand-graded roads difficult. In the Amazon valley seasonal flooding and marshy lowlands combine with unmastered forest to make most overland transportation impossible. North-south mountains in South and Central America, with unmanageable slopes and few divides, limit east-west transportation linkage throughout tropical America.

Thus in a machine age inhabitants of the tropics still move and ship by means old centuries ago. Rain-forest areas depend almost solely upon rivers as their arteries of communication, and the entire Amazon valley, a continent within a continent, relies exclusively upon ancient packets and inefficient wood-burning steamers to run the larger streams. Beyond this, small launches and finally dugout canoes carry supplies to and remove produce from the distant isolated settlements. No wonder that weeks elapse and prices soar as merchandise traverses the thousands of miles of muddy water from Belem at the mouth of the Amazon to the upper reaches of this gigantic stream system in Colombia, Peru and middle Brazil. No economical and, with the exception of aircraft, no effective transportation has conquered the north-south mountains. Andean countries rely upon human runners of Indian ancestry or occasional llama trains to traverse the towering mountains. It is found cheaper to transport products from Amazonian to Pacific-slope Peru via the Amazon river, Caribbean Sea, Panama Canal and Pacific Ocean, a distance of thousands of miles, than over the Andes, a few hundred miles. In eastern Brazil only a few unkept roads, impassable to modern cars, connect the populated coastal belt with the Sao Francisco valley, and beyond that not even this much exists. Transportation must be along the frequently seasonal rivers or overland by mule or on foot. During the dry season even mule passage becomes impossible for lack of forage enroute. For short distances, not more than a few hundred miles, slow and generally dirty wood-burning railroads are available, the most efficient transportation in the Canal Zone, at intervals along the coast of South America, and in Costa Rica and other Central American countries. Tropical America on the whole remains dreadfully inadequate in transportation, relying to this day upon human carriers, beast-of-burden and very scattered water, rail or truck transportation to bring expensively to market the wealth of hinterland plant products. This situation is perhaps the greatest single obstacle inhibiting successful exploitation of the lush tropical vegetation.

Organizations exploiting large concessions or opening new areas for exploitation in tropical America are faced with establishing their own microcosm of a transportation network. Even then, when the many human and climatic considerations yet to be discussed have been taken into account and provision for adequate capital made, irritating difficulties and delays are apt to come up because of no reliable information concerning the terrain. Existing maps are usually partly or wholly of guesswork, with elevations, soil or rock types, river courses, *etc.* frequently inaccurate or not considered. Outfits opening concessions in the tropics ordinarily must map and survey before intelligent planning for local transportation becomes possible. All of this eventually adds up to higher costs.

Maintenance

Maintenance of equipment in the tropics is a more serious concern than for temperate regions. Two aspects of maintenance become apparent: *a*) physical breakdown under climates conducive to deterioration and in regions deficient in mechanical facilities; *b*) the securing and keeping of competent maintenance crews or supervision.

In the former case it is apparent that the warm humid climates generally prevailing in the tropics accentuate rusting, molding, *etc.* on equipment manufactured in and designed for temperate climates. Moreover, much of the equipment must be put to overly severe use, due to poor roads, seasonal hurry-up, unavailability of replacements and constant unforeseen demand for work for which the equipment was not specifically designed. With the typical lack of repair facilities, high-quality parts, high-grade fuels and skilled operators, it is no wonder at all that the average life of any piece of equipment may be but a fraction of its working life under temperate conditions for which it is designed. The life of a jeep may be less than 15,000 miles, and heavy equipment may survive only a few rainy seasons.

The second aspect, that of maintenance, largely influences the first. Skilled and imaginative mechanics can easily double the working life normal to most equipment operative under tropical conditions. I have seen 1929 Fords 15 years old, literally pieced together with baling wire and locally-fashioned parts, make 3,000 mile trips through eastern Brazil over "roads" impassable to any modern car. On the other hand, new motor vehicles have remained stalled for protracted periods and have even been ruined under water because the operator possessed no mechanical background of as simple a nature as understanding battery and carbureter connections. The difficulty in the tropics is in finding sufficient personnel with mechanical understanding, interest and skill. In the United States almost everyone has been associated to a greater or lesser degree with mechanical devices and automobiles since childhood, and understands the basic principles upon which these devices are constructed. On the other hand, the great majority of Latin Americans have never been able to afford mechanical equipment, and those wealthy enough to possess it look askance at soiling their hands over its upkeep. By and large their interests lie more in politics and the arts than in science and engineering. The result is a paucity of trained and experienced mechanics among Latin peoples, and consequent deficient upkeep of equipment. If United States mechanics or supervisors are brought to the tropics, not only must their wages be considerably higher than in the U. S. A., but their stay is apt to be very transitory and their attitude toward Latin conditions unsympathetic. Causes of dissatisfaction will be reviewed in a later paragraph.

Supplies

In most parts of tropical America adequate supplies by United States standards are non-existent. Common medicinals, if available at all, may sell for many times their value at the corner drugstore in the U. S. A. Repair parts for mechanical equipment are available only in the larger centers. Over much of the region life exists on a self-sustaining basis, with reliance on the outside only for such necessities as guns and ammunition, machetes, cloth and occasional foods or tools. There are many interior villages in Central and South America where nothing can be purchased, not even local foods. Food supply is often deficient because growing of crops is largely by laborious hand methods. No large-scale or mechanical farming methods exist to permit abundant production at lowered costs. Quality food remains scarce and expensive. In the upper reaches of the Amazon waterway basic supplies from the outside eventually reach the outposts of civilization, but selection is very limited and costs usually prohibitive for the average laborer or rubber tapper of the region. Most jungle inhabitants must rely for food upon wild game plus what they can grow. They work with make-shift equipment and live in the humblest of housing. Obviously no trained North American, accustomed to the ways of the U. S. A., will be content to stay for protracted periods in primitive areas such as these. Nor will educated citizens of the country in question find it profitable to do so. Consequently the quality of supervision so sadly needed for efficient exploitation in backwards localities becomes unavailable because lack of supplies does not allow for adequate standard-of-living. In order to keep trained personnel satisfied and equipment properly serviced, organizations operative in the tropics have ordinarily to maintain their own supply and fuel depots, housing projects, medical service and even "country clubs." With permanent or elaborate undertakings it may frequently be necessary to construct sanitation systems, water purification plants, ice houses, tooling plants, *etc.* Seldom are such subsidiary projects self-sustaining, and the added overhead must be further taken into account in the cost of the product being exploited.

Seasonal Operation

In many parts of Latin America seasonal cycles make it impossible to extract products of the forest during parts of the year. Rubber, Brazil nuts, mahogany and various other woods cannot be reached during flood stage in the Amazon valley. Commerce in vegetable products comes almost to a standstill for a few months of the year. In eastern Brazil gathering of secondary latices ceases during the dry season, due to insufficient yields and injury to the plants, while commerce in palm wax gives poor yields in times of abundant rainfall. Gathering of chicle for chewing gum in the Yucatan area can proceed only during a part of the year, while various logging operations demand seasonal river floodings to float logs to market. Many roads become impassable during the rainy season. These factors tend to make production difficult and delivery uncertain. Seldom can a product be held over in tropical climates without deterioration if transportation becomes disrupted by seasonal change. A shortened productive season throws added burden on the productive months to average out annual costs. Equipment is more severely used, seasonal labor must be sought and overhead sustained during the non-productive season. Of course, maintenance and supply problems are thus further aggravated.

Operational History

Exploitation of the natural vegetation of Latin America has been practiced for centuries. Quebracho for tannin has long come from Paraguayan forests, rubber from wild trees of many genera and species throughout Central and South America, mahogany and other woods from tropical American forests, haematoxylon and Brazilwood dyes from many lowland regions, quinine from Andean countries, balsa from Pacific South America and Central America, kapok, chicle, several resins (copal), *etc.* from various parts of the American tropics. The history of exploitation is in each case the same—one of taking all available material wherever it could be reached, with little or no thought for future supply. As a result, high-quality logs, rubber trees, tannin sources or whatnot have been eliminated in populated and accessible localities. Remaining stands are distant in the hinterland—inaccessible, of unknown extent, a considerable commercial risk. Year by year this situation becomes more aggravated resulting in added burden upon transportation, maintenance and supply to effect collection from wild sources.

Equally disturbing is the persistent practice of selective removal of wild plants from the diverse forest areas of the tropics. Mahogany or rubber or chicle may occur naturally with a frequency of perhaps one tree per acre. Few mahogany, rubber or chicle trees can be found today in relatively accessible forests where exploitation has been carried on many years. During the history of exploitation of the American tropics it has always been the practice to remove or kill in tapping only the finest species and the finest trees of that species. Consequently these valuable types are at a disadvantage for reproducing themselves. No sooner is a fine specimen removed than a jungle of less desirable types, not felled nor inhibited, closes in to usurp the habitat. Within the species desirable high-yielding specimens have been persistently tapped, and thus a significant percentage of them killed, or have been selected for cutting, leaving poorer individuals to reproduce the kind. Jequié manicoba (rubber) in Baia, Brazil, offers an excellent example of this type of worsening in the stand. The frequency of poor-yielding trees noticeably increased with only three years of heavy tapping. With exploitation involving removal of trees, culls and valueless types are left to hold the area where otherwise robust individuals of desirable types might be growing. Logging in Central America well illustrates this type of stand deterioration. For such reasons species have decreased in quality as well as quantity over tropical America as a whole, a situation, however, by no means limited to the tropics.

Another facet of exploitation reflected in increased cost is the tremendous wastage involved with tropical plants. An entire tree may be sacrificed to yield a few fruits, a few cupfuls of latex or one or two high-quality logs. In lumbering in isolated forest areas of South America, for example, fine trunks of expensive cabinet woods are hand-trimmed to a square shape, during which operation all sapwood and as much as one-third of the heartwood, to say nothing of tops and branches, are lost as chips and slash. If squared logs are to be sawed, two laborers in a sawpit, one above, the other below the log, tediously produce a plank or two per day and nearly as much sawdust with a two-man buck saw. Thus, unless an efficiently organized production company can control operations to the very source, and supply supervision in the remotest parts of a concession, excessive wastage of the resources becomes inevitable. The greater the wastage the sooner will supplies be exhausted and the sooner transportation or other permanent improvements will have to be written-off as capital loss.

A final word on operational history might stress the ingrained habit of seemingly all uneducated tropical peoples of burning-over the landscapes. Wherever a prolonged dry season makes forest or grassland dry enough to sustain fire, fire is invariably set year after year. The result is, of course, injury to soil and standing plants, inhibition of proper reproduction, elimination of game, and favoring of those species with thick enough bark or resistant enough seeds to withstand fire. In Minas Geraes, Brazil, during the dry season, there is a persistent haze often as dark as United States industrial "smogs" over the entire State for days on end. And in the thin marginal forests of the State, gnarled thick-barked trees, decades old but no larger than one's arm, attest the effectiveness of the annual burning. To control annual burning, reason and Federal law alike are of no avail; only competent supervision can stop the practice. Fortunately, over most of the tropics, rainforest never becomes sufficiently dry to kindle.

Diversity in Tropical Vegetation

In contrast to temperate forests with few and very abundant dominant species, tropical forests generally contain hundreds if not thousands of kinds of plants in a frequency seldom greater than one or two per acre. Marginal forests and grasslands behave more as do temperate climate plant populations in this respect. If tropical forests are to be exploited for one or few plant products only, as has traditionally been the practice, immense tracts are necessary to maintain adequate supply. Quite obviously there are then further demands on transportation and maintenance. This inherent difference between tropical and temperate forests is often not realized by North American producers. In lumbering, for example, it becomes easily possible in the southeastern U. S. A. to reap from a moderate acreage commercial quantities of southern yellow pine with practically no other species. In the Amazon valley the same acreage might give scores of species, none in commercial volumes, many of them unknown on the market and unsalable if harvested. The same would be true of gathering nuts, fruits, medicinals, latex, resins, tannins, *etc.*, *etc.* Costs of extraction, involving, as one item, road opening, must therefore be carefully weighed against volume procurable in tropical forests, and for greatest economy effort must be made to find uses for and acceptance of a wide variety of arborescent types.

Vegetational Resource Evaluation

Most of tropical America is poorly known botanically. Hundreds of new species await discovery, particularly in the Amazon country, and thousands more await critical evaluation. Only Guatemala, Costa Rica and Panama have been, or are in the process of being, critically reviewed floristically in modern times. Relationships between Central American and South American species are extremely uncertain. A comprehensive knowledge of the tropical flora is still many years away. Equally untouched are ecological studies and concomittant records of species frequency, habitats and rates of growth. Factors governing regeneration of individual species are largely unanalyzed. Studies on plant diseases, soil development and climatic influence are all still in their infancy. This paucity of botanical information, coupled with large unexplored areas, inaccurate maps and dubious or contradictory local information, makes accurate planning of large-scale long-term exploitation of wild plants impossible, unless first there is conducted an expensive preliminary survey. As a result, most ventures by sound established organizations in the American tropics have relied upon well-known cultivated exotics as the basic crop—bananas, coffee, sisal, abacá, cacao, *etc.* Where native wild plants are utilized they typically reach market from isolated sources through general exporters who have no control over and often no knowledge of production.

Tradition of Exploitation

For so long have the American tropics been wrested of their vegetational wealth with no regard for the future, that practically no spirit of conservation rests with the people. Mention has already been made of several specific malpractices. More alarming is the general disregard for conservation. Steep hillsides are denuded, watershed cover wantonly destroyed, .species reduced to near extinction, with seldom a voice raised in protest. Any outside organization interested in controlled exploitation of the tropics can expect in its own interest and that of the country in which it is operative, to have to enforce even elementary conservation practices upon local employees.

Capital and Credit Difficulties

Operations in the American tropics financed by United States interests are little concerned with capital and credit problems in the Latin American countries. Yet small producers operative within the tropical countries may find capital hard to obtain and interest rates high. Financing is such in many localities that bank interest on savings may draw as high as 10% interest. Away from the relatively few cities financing may be so primitive that "grubstaking" by certain merchants with payment in produce is the accepted procedure among the illiterate populations dwelling there. Financing conditions are perhaps analogous to those of the United States a century ago.

Paucity of Manufacture

In most of tropical America manufacturing is non-existant. What little there is is in most countries definitely inferior to and usually more expensive than that of the U. S. A. or Europe. As a result there exists general dependence for manufactured goods and ultimate markets for products of the wild upon distant temperate zone cities. Long transportation hauls and much handling become necessary, with added cost to both articles purchased and produce sold. Uncertainty of supply also frequently occurs, particularly in times of emergency, as prevailed during the recent war. Lack of local manufacture, of course, has a bearing upon problems of supply and maintenance.

Labor

Among human and political factors affecting production from wild plant sources in Latin America, labor is certainly of moment. In long-settled localities—the coastal regions of South America, the Canal Zone, the "meseta central" of Costa Rica, Salvador and the more healthful parts of northern Central America, most of the West Indies—labor is available in quantity. On the other hand, in the Amazon and Guiana wildernesses and in other areas already mentioned as deficient in transportation, quantity of labor for concerted conquering of the jungle is lacking. And production of any native resource from these areas is only as good as the tapper, axeman or collector who today haphazardly gathers marketable vegetable produce in order to secure modest supplies from the small interior exporter. On the whole, labor must be regarded deficient in tropical America, the areas of deficiency correlating with areas insufficient in transportation, supplies, *etc.* Where populations are abundant, wild plants of value have largely been eliminated. One of the greatest difficulties in securing large and constant amounts of strategic materials from the wild during the last war was the problem of getting labor in large quantity into remote locations, and of maintaining the workers there. Certainly from the standpoint of availability, labor resources over most of Latin America cannot compete with those of the Far East.

By and large, New World tropical labor is not dependable. The pace of life is slow, and a tradition of laxity and absenteeism exists. What matter if a construction project takes months instead of weeks! Tomorrow is always another day. Moreover, seldom does a week pass without at least one or two excuses for a holiday, if nothing more than in honor of a patron saint or in deference to the death of a distant relative. Many national holidays are celebrated twice or more times, as, for example, on the eventful day itself and again on the day the news of the happening reached local districts. In wilderness regions, such as interior South America, frequent holidays even become a necessity for securing game, constructing dwellings, fetching supplies.

In any country of Latin America a commitment is not to be taken too seriously. An appointment for eight o'clock likely means ten, or even the next day, and an agreement to work may or may not result in appearance of the worker. Amount of work is calibrated to necessities for existence: if five dollars per week is necessary to survival, just so many days work as is required to obtain five dollars will be undertaken—no more. One of the most fantastic episodes of war-time dealings in South America showed U. S. A. union wages offered to native workers for certain construction work, several times the average wage in the locality. The result was wholesale abandonment of customary employment, to work for the U. S. A.—one day a week and loaf five. There was during the short interval that this policy was in effect an unmanageable turn-over of workers, the garnering of carloads of ill-will from local employers, and the U. S. A. agency itself made the laughing stock of the workers. It was certainly not the road towards gaining Latin American good will for the U. S. A. My personal experience in Brazil showed repeatedly that for maximum production a wage scale equal to or slightly better than that for any other activity must be maintained to lure workers to the field, but that anything beyond such an optimum will result in increased opportunity to loaf, a factor of considerable significance where labor is scarce. With "ambition" in the United States' sense usually absent in the workers, the traditional system of myriads of middlemen "exporters" exploiting the ignorant forest inhabitant to the utmost has probably been the most efficient for quantity production of wild vegetable materials. Tropical American unskilled labor typically lives in poverty and has learned through generations to expect nothing more. Yet this labor cannot be "driven," as reportedly can African labor; it must be made to "want to work", albeit often by force of necessity.

Manual skill of the average tropical American laborer is said to be inferior to that of the Far East, about equal to that of Africa. It is difficult to teach exacting procedures, and impossible to alter traditional practices. "What was good enough for gran'pappy is good enough for me'' is the typical outlook. Appeal by reason for improved practice is of no avail. Since adequate supervision is usually impossible in extraction of wild products, there is little hope for improvement of methods. Yet these same traits of stubbornness and tenacity often are reflected in considerable loyalty to an employer in favor. Many are the cases where higher wages have been of less decisiveness than compatability of employer in determining acceptance of employment. And if a sincere desire to do the job exists, tropical American labor can be as industrious for short periods as that in any other region of the world.

Unskilled labor costs are not great in comparison with United States standards, but are considerably higher than those for Africa or the Far East. In pre-war tropical America daily wages ran from as little as a few cents to a high seldom over one dollar. Very localized areas, such as oil developments in Venezuela, may have wages well above the usual. During the war years a typical wage in interior Brazil did not exceed twenty-five cents per day. Organization of labor has not as yet become general in Latin America, so that unionism is seldom a factor demanding consideration. Certainly in the unpopulated areas where wild plant products are typically gathered, labor organization is an impossibility. Skilled labor through much of tropical America is extremely scarce. Most of the population has little or no educational opportunity and away from the few large cities remains illiterate, subject to many superstitions, rumors and unsound practices. The absence of a conspicuous ''middle class'' results in a wealthy educated minority, unwilling to soil their hands, and a poor uneducated majority without possibility for gaining experience in skills. Few mechanics or machine operators are obtainable from native populations.

Except with domestic help there is seldom assumed any responsibility for housing or keep of labor. Yet a progressive concern intent upon exploiting the richness of remote tropical America would have to consider this problem as well as those of transportation and equipment. For prolonged operations no labor can be kept without family. To keep laborer and family reasonably efficient and content, housing, commissaries and perhaps even medical service become necessary, the same as is necessary on plantations. As a rule these need not be elaborate. Latin American labor is traditionally content with meager housing, one or two basic foodstuffs and very little hygiene. It is often to the employer's interest to maintain health service, for malaria alone may otherwise materially reduce man-hours of labor possible from each worker, while general efficiency of the worker may become undermined by a series of tropical illnesses. As inexpensive an undertaking as supply of quinine or atabrine to isolated workers, free or at cost, can significantly increase productiveness per worker. This becomes a matter of importance where labor is scarce.

Supervision

Proper supervision of undependable illiterate labor is much needed in the tropics. Yet seldom can it be obtained in the remote regions where wild plants are exploited. Even if occasional trained national personnel can be found, seldom can conditions in the remote districts be made sufficiently attractive to interest these men obviously capable of making their way in more civilized places. They are more exacting in their requirements for housing and supplies, and are frequently of child-like undependability in completing a job under difficulties. On the other hand, the bringing-in of temperate zone supervision from the U. S. A. or Europe offers a great many difficulties. Such supervisors must be well paid, must be more elaborately provided-for than local peoples, and in many cases prove temperamental or incompatible with local customs and tropical living. Seldom are they satisfied in their work for more than a few years. So far, therefore, it has been impractical to bring in temperate zone personnel except to established plantations. An occasional "lone wolf" will make his living by organizing exploitation of wild plant products, and in the process usually "goes native."

Management

Local management in tropical countries, through knowledge of language, customs and political experience, is perhaps more capable in organizing extraction of wild plants and plant products than is foreign management. Yet local management may be less dependable financially and less efficient in gaining world markets. Moreover, there is perhaps more frequently a tendency with local management in the American tropics to show undue ostentation, engage more freely in graft, seek monopolism and high prices, and demonstrate the usual social apathy. Any of these practices may directly or indirectly inhibit production. Local management has infrequently risen from the ranks. There is typically a lack of broad background in technical or mechanical training, and often in integrated knowledge of all procedures of procurement. In times of stress such management may be less likely to provide needed foresight, steadiness and strength.

On the other hand, management by temperate zone groups involves operation from considerable distances, and often embraces unfamiliarity with local conditions and with the Spanish or Portuguese languages. Inexperienced North Americans invading the commerce of the tropics have at times cut a sorry figure depending upon interpreters, demanding "their rights as Americans," constantly making known how inferior they regard everything outside of the U. S. A., and depending solely upon a heavy bank account to command respect. They and their families frequently cannot endure tropical life for long, and in spite of individual capability cannot manage a tropical enterprise with enthusiasm.

Political Uncertainty

Political steadiness has never been achieved in Latin America. Governments and policies "in" today may be "out" tomorrow. Concessions granted for prolonged periods under stipulated terms may become rescinded in short order. Groups enjoying the favor of one administration may suddenly be on the wrong side of the fence. Under such conditions heavy capital outlay becomes a considerable risk. Political reasons alone are sometimes sufficient to discourage North American capital investment in tropical enterprise. With the recent nationalistic trend in Latin America most North American investment is best made through subsidiaries incorporated under the laws of the country where operative and at least nominally in the charge of nationals.

Ephemeral Governments may meddle unduly in the operations of a successful enterprise. Political appointees try to make the most of their potentially brief stay in office, and look upon a money-making industry with hope. Taxes and export duties may become increased, or behind-the-scenes payments demanded to obtain necessary permits. Such Governments seldom accept their responsibility to the nation, nor do they realize the urgency of conservation measures. Many officials are more concerned with lining their own pockets than furthering the interests of the State. Even where top Government policy fosters intelligent exploitation of wild plant products and State laws are enacted to regulate practices, seldom can such directives be supervised in the remote districts where wild plants are found. This passage of unenforceable laws breeds contempt of all regulation, and commonly conservation directives are ignored, and inspectors, if any, payed-off when advantageous.

Militarism

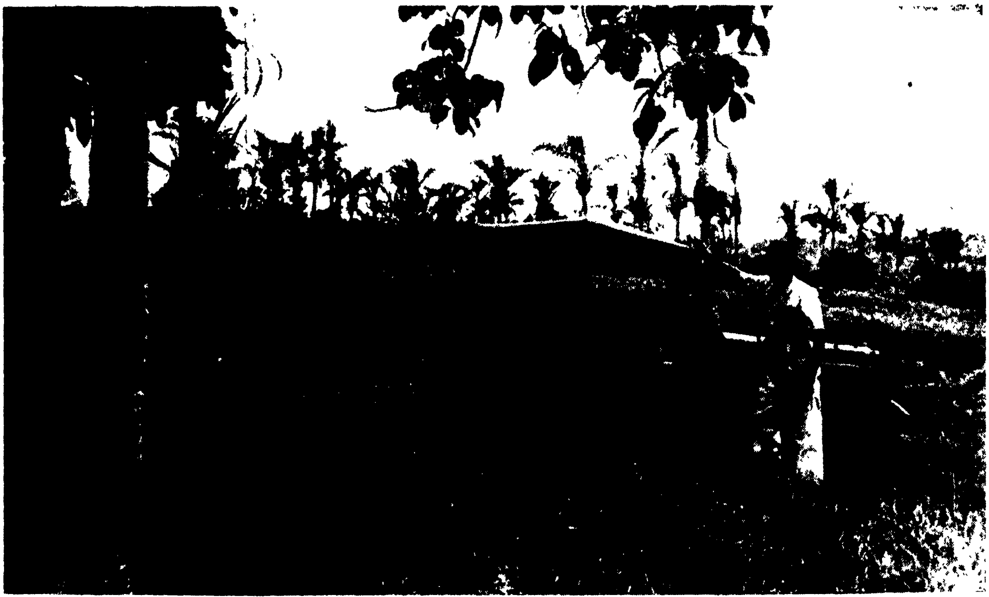
Many Latin American countries are dominated by the military which may or may not be sympathetic to civilian enterprise. An extreme example of a deterring influence by the military upon flow of a plant product, in this case salvage, occurred in Brazil during the recent war. German boats attempting to run the Allied blockade had been sunk in the south Atlantic, and bales of Far Eastern rubber began to wash-up on the Brazilian coast. The coastal population found it quite lucrative to salvage these bales for sale to the Allied rubber pool. Suddenly coastal military commanders ordered that all salvage was property of the army (the commanders ?), and took over rubber found in the hands of the uneducated beachcombers, even at the point of a gun. So terrified were some rural populations that they buried badly needed rubber in the forest rather than be caught with it, and made no effort to seek additional bales.

Nationalism and Customs Difficulties

Only those who have traveled through the multitude of small Central American Republics can realize the almost endless red-tape of documents, seals, official signatures and permits needed to transact the simplest of business or engage in any significant commerce or travel. It often becomes cheaper simply to bribe the ultimate dispatcher where possible than to go through the maze of regular channels. Many exporting concerns keep on the payroll a relative of high officials to "arrange" for the necessary documents. The feeling of nationalism is high, and many minor officials take particular pride in showing their authority. Customs and export difficulties may seem onerous in the U. S. A., but they are nothing compared to those of most Latin American countries. On small shipments or infrequent items, as many wild plant products are apt to be, cost of exporting by common carrier, including time spent in red-tape delay, may exceed production cost of the item. Nor is pilfering in transit or during unsupervised inspection uncommon.

World Acceptance of Product

Mention has already been made of the diversity of plant life in the tropics. A few species are much utilized and thoroughly known on the world market. Yet, if the many other species found in the wild could also be profitably harvested, production costs from a given area might be materially reduced. It is a problem before tropical exporters to make known or discover uses for the multitudes of potentially useful tropical plant species. Unfortunately the usual condition with wild plants is one of insufficient steady supply to interest large manufacturers. Under such circumstances it becomes difficult to build up a market in competition with cultivated plants from steady sources. Another point militating against new introductions is the human tendency to resist change. Labor accustomed to certain



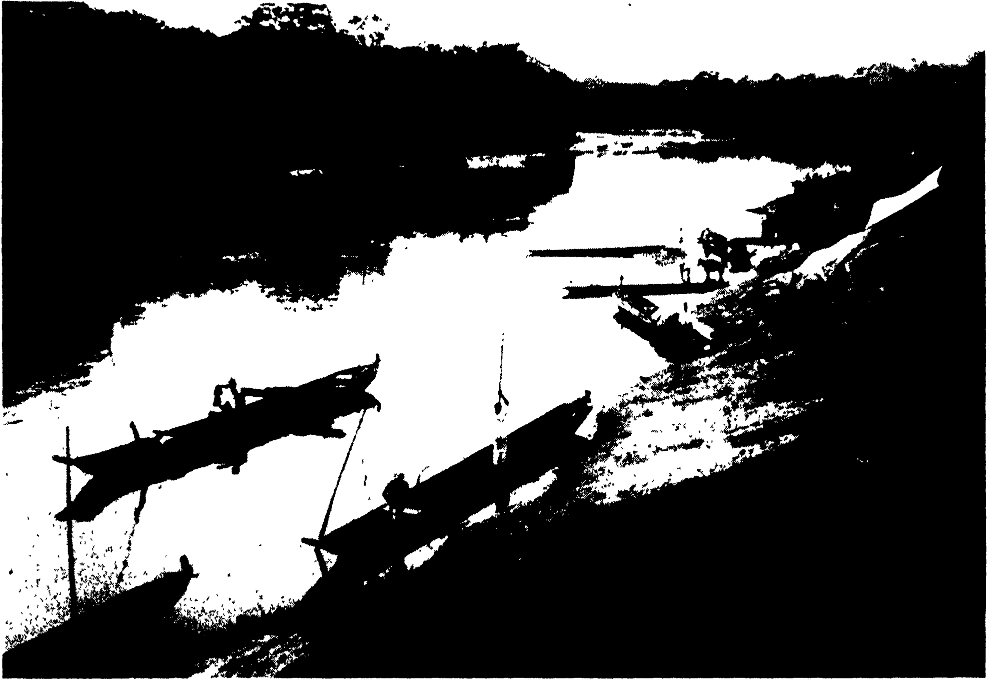


FIG. 1 (*Upper*). Ouricuri palms (*Cocos coronata*), a source of wax and oil, in the vast palm belt of Brazil. Broad-leaved foliage is that of a fig (*Ficus* sp.)

FIG. 2 (*Lower*). A typical method of transport in rainforest areas beyond which steamboats can not travel up the shallow rivers. Here the Rio Pardo in southern Baía, Brazil, is the only link from the interior to the sea and coastal civilization.

FIG. 3 (*Upper*). Evidence in eastern Brazil of the Latin American traditional habit of burning forest areas without regard for useful vegetation, merely to clear land for planting manioc, or cassava (*Manihot esculenta*).

FIG. 4 (*Lower*). Scrub land in east-central Brazil where gums and secondary latices are obtained from wild plants.

procedures and graders familiar with certain types are reluctant to accept novelty. Furthermore, elaborate factory machinery involving considerable capital investment may be unsuited to other than one type of raw material. Machines for scutching flax, for example, will not efficiently scutch milkweed.

FIG. 5. Panama rubber trees (*Castilla elastica*) tapped by the natives in local fashion of the Costa Rican rainforest.

Miscellaneous Local Difficulties

Various local happenings may effect production from wild sources. Inclement weather, epidemics of disease, fear of wild animals, *etc.* may effectively reduce the output in any remote district. In portions of the unchartered jungles of South America, hostile Indians may to this day prevent free movement of unescorted individuals. Evidently much wild rubber is to be found along the headwaters of the Tapajos and Xingu in northern Mato Grosso, but tappers can only skirt the fringes of the area for fear of their lives. During wartime, when rubber was at a premium, several tappers in this region fell before poison darts or arrows.

Summary

All in all, expoitation of tropical plants, particularly from the wild, involves inordinate risk when balanced against possible gain. Therefore, although the American tropics have been known to the white man as long as has North America, progress in utilizing the vegetational resources is far behind that of the temperate zone. Part of the difficulty is physiographical, where swamps and steep slopes mitigate against transportation and agriculture alike, and part is climatological, where debilitation is common and proven agricultural techniques are difficult. Spanish and Portuguese tradition perhaps centralized authority too greatly, and permits or even encourages excesses in politics and land management. The stimulating intermixture of northern European populations has been notably absent.

In view of the many accentuated difficulties discussed in the previous pages, it is no wonder that North American capital has been hesitant to venture into exploitation of wild tropical resources. At the same time local efforts have been largely without success in conquering the immensity of the fast-growing forests. It would appear likely that little promise can be held for large-scale exploitation of any wild products from tropical America with the exception of lumber. It is perhaps inevitable that with the rapid destruction of North American forests, the economy of the U. S. A. will turn to the vast tropical hardwood forests of Latin America for part of its lumber supply. Other products from the wild will likely continue to be marketed in a desultory fashion, with supply and demand both uncertain. No plant adaptable to cultivation but grown only in the wild can long withstand plantation competition from the Far East.

Utilization Abstract

Tall Oil. Tall oil is a by-product of pinewood paper-pulp manufacture. In 1948 about 250 million pounds of it were produced in the United States, and the products made with the oil include adhesives, asphalt emulsions and wetting agents, binders, boring oils, cement addition agents, cleansers, core oils, cutting oils, disinfectants, drawing oils, emulsifiers, factices, flotation reagents, fungicides, gloss oils, greases, grinding acids, linoleum, mold lubricants, oilcloth, paint driers, paint oils, paper sizes, penetrating oils, pigment wetting agents, plasticizers, polishers, printing inks, resins, rubber chemicals, soaps, soluble oils, sulfonated oils, textile oils, varnishes, waterproofing agents and wetting agents. The quickly constructed landing fields of the recent war, laid out in swampy land and strong enough for bombers, were made possible by small amounts of tall oil in the paving which induced the wet earth to dewater itself and to stick to the asphalt.

The oil consists of varying mixtures of fatty acids, rosin acids and minor amounts of other substances. It exists in the pine logs delivered to pulp mills to the extent of only about one per cent. Each producer offers his output with accompanying specifications, and consumers select the grades best suited to their needs. Some tall oil was made in Sweden at the beginning of the present century, and in 1909 a U. S. patent was issued for its manufacture, but American production did not begin until 1930. Previously it was a waste product and a nuisance.

Tall oil is the lowest priced of all organic acids, and in addition to its many uses already noted, it is a low-priced source of its components, abietic acid in unpolymerized form, oleic and linoleic acids, and sterols. (Arthur Pollak, *Chemurgic Digest 8(6): 8. 1949*).

Safflower. Commercial production of safflower (*Carthamus tinctorus*) as an oilseed crop in the United States has begun in Nebraska, northeastern Colorado, western North Dakota and eastern Montana, and is being considered in parts of Oregon, Washington and California. Recent development of new varieties with seeds averaging more than 30% oil gives safflower a good chance of becoming an important oilseed crop in the United States. Sufficient seed is expected to be available for planting 100,000 acres in 1950. Markets for the seed have been established by Western Solvents, Inc., of Longmont, Colorado, and Chemical Crops, Inc., of Scottsbluff, Nebraska. (C. A. Claassen, *Neb. Agr. Exp. Sta., Circ. 87. 1949*).

Herculin. Hot water or acetone extracts of bark, leaves, berries and roots of various species of *Zanthoxylum* have at different times been reported to be insecticidal, and in 1943 a patent was granted for use of the root, bark, leaves and fruit of southern prickly ash (*Z. clava-herculis*) as an insecticide. An active substance has been isolated from this bark and named "herculin". Asarinin, previously isolated from the bark, has been shown to increase the effectiveness of pyrethrum solutions.

"*Z. clava-herculis* . . . commonly called southern prickly ash, Hercule's club, or toothache tree, is indigenous to the southern United States. The bark is used medicinally as an irritant and stomachic, and is available commercially. Chewing of various parts of the plant, especially the bark, gives a persistent, burning, paralyzing sensation on the lips and tongue, an effect also given by *Z. acanthopodium*, fruits of *Z. piperitum*, and the bark of *Z. macrophyllum*, all of which are used as analgesics, particularly in cases of toothache". (Martin Jacobson, *Jour. Am. Chem. Soc. 70: 4232. 1949*).

IRISH MOSS—*From an Art to an Industry*

This red alga, harvested commercially along the shores of Prince Edward Island, Nova Scotia and New England, is today processed by five American companies into an extractive that finds a major market as a stabilizer in dairy products and enters also into the manufacture of a variety of other products ranging from beer to toothpaste.

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Introduction

The recognition and utilization of Irish moss in New England has been well documented. This surge of prose does not mark the start of a new era but merely tags one of the branches of an art whose roots are lost in antiquity. Family recipes and remedies carried along by word of mouth from mother to daughter and father to son have utilized this wild crop of the North Atlantic. What is more natural than that the French, Scotch and Irish, migrating to the western shores of the North Atlantic, should have recognized and utilized this crop.

As long as the use of Irish moss remained an art, the preparation and purchase of this commodity were restricted to those in the line of succession. It was to be expected that France and Ireland should become the major sources of supply with minor sources burgeoning in New England and Nova Scotia. Sales were confined principally to family type recipes, remedies and industries.

It was the enterprise of American industry that first found new uses for an old material, which naturally was purchased from the major processors in Europe. When the war cut off European imports it was this enterprise that pushed the expansion of domestic sources. The war at the same time cut off supplies of imported gums, such as agar, tragacanth, arabic and acacia. It did not take long to determine that the active ingredient from Irish moss could replace these gums and in many instances outperform them. Spurred on by wartime needs, old equipment was adapted to the processing of moss, and a purified hydrocolloid, obtained as a hot-water extractive from these algae, was placed on the market. Today five American companies[1] are actively engaged in the preparation of purified Irish moss extractive, and a far greater poundage of extractive is being marketed now than of crude moss before the war.

Newly developed sources of Irish moss and greatly expanded old ones did not at once begin to produce raw material of the same high quality as had been imported. Hastily devised processing methods did not at once produce the best possible finished product from the raw material available. But great strides have been taken in both directions. The finished product today is far superior to that of even two years ago, and Irish moss extractive is well entrenched as a valuable peacetime commodity.

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[1] Krim-Ko Corp., New Bedford, Mass; Kraft Foods Co., Chicago, Ill.; Jacques Wolf & Co., Inc., Passaic, N. J.; Bowey's Incorporated, Chicago, Ill.; Algin Corp. of America, New York, N. Y.

The Plants

The raw material for this industry, *Chondrus crispus* (L.) Stackh., is variously known as Irish moss, carrageen or carrageen moss—the name carrageen deriving from a town in Ireland which was long an important shipping point for the product. *Chondrus crispus* belongs to the family Gigartinaceae in the class Rhodophyceae, or red algae. Another species in the same family, *Gigartina stellata,* has at times been substituted for *Chondrus crispus*, particularly in Ireland, England and Norway. True Irish moss grows from a tiny disclike holdfast, often achieving a length of about eight inches, forming loose to often dense clumps of a dark red-purple coloration. The slender stalk expands sharply to a flat wedge-shaped apex which is divided dichotomously. Segments continue dichotomous branching to eventually form dense heads. Apices of the branches are rounded, and the margins are entire. Tetrasporangia are found in irregular, solitary, little swollen dark red sori in the terminal segments. Cystocarps are located in similar sori.

Although most *Chondrus* will be found growing in dense masses on the sublittoral faces of rock formations in cold, open water, usually just below a growth of rockweed, a sufficient number of anomalies exist to confuse the botanist. An area of Quincy Bay in Boston Harbor, year after year, is covered with a heavy growth of Irish moss in spite of warm shallow protected water and mud bottom. The plants attach to miscellaneous solid objects such as shells, cans, worm tubes and small stones. The growth and pigmentation are similar to what is observed under "normal" conditions, and the incidence of reproductive organs seems much greater. The brackish waters of Scituate harbor in Massachusetts and Charlottetown harbor in Prince Edward Island frequently support heavy growths. Many more such situations probably exist. Contrasted to these situations, extensive beds of *Chondrus* have been reported by divers at depths as low as 40 feet off the coasts of Maine and Massachusetts. Yet in spite of the seeming hardihood of the plant, attempts at artificial cultivation have failed dismally.

Another anomaly exists in pigmentation. The position of *Chondrus* among the red algae could hardly be guessed from an extensive growth occurring off Point Prim, Prince Edward Island. Here a dwarfed form which covers a shallow red sandstone shelf reaching ten miles out into the Gulf of St. Lawrence toward Nova Scotia, is entirely green. No red pigmentation has been observed in any "moss" from this area.

Lack of pigmentation is often attributed to differences in intensity of illumination, but such an explanation could hardly suffice here.

Harvesting

Today's Irish moss industry is being supplied primarily with raw material from the North American coast. The main centers for harvesting and purchase are at Scituate, Mass.; Rockland, Maine; Yarmouth, Nova Scotia; and Prince Edward Island. On Prince Edward Island most of the harvest is driftweed thrown up on the northern shores in huge windrows whenever the wind blows from the North. Some driftweed is also harvested at Point Prim on the southeast shore. At times when the winds are uncooperative some moss is raked at Point Prim and near Tignish on the northwestern extremity of Prince Edward Island.

Raking is the primary means for harvesting Irish moss in Nova Scotia, Maine and Massachusetts. A taper-toothed rake on a long handle is manipulated by hand from a dory to tear the *Chondrus* from rock formations made accessible at low tide. Some skill is required for this operation, since the rakes have 18-foot handles and only the pull of the rake is used to keep the dory in position while working. A skilled man can rake 800 to 1,000 pounds of wet moss on a tide, for which he may receive from 1¼¢ to 1¾¢ per pound. Reports of two to three harvests off the same rock face would indicate an extremely rapid rate of regrowth. Controlled experiments indicate, however, that the reports may be true but the conclusions false. When a plant is pulled or broken loose, the holdfast still remains firmly attached. Regrowth starts from the holdfast, excellent insurance for an uninterrupted crop, since there is no dependence on spore or gamete survival and germination. Natural reproduction by means of spores requires six to eight weeks from germination to completion of the holdfast, and a full year from the holdfast to a size suitable for raking.

Raking does not denude the rock but only tears off the larger growths. More room is left for the smaller plants. With an excess of nutrient the growth rate of a branching plant increases geometrically so that several harvests in one season from one rock face are easily possible under these conditions.

The season for raking depends on the weather and usually extends from May until September. At other times, the water is too rough. Rough weather with winds from the proper direction are required for drift moss. The season on Prince Edward Island usually extends from August to November. Another limitation at present is the need for good drying weather, since the geography and economics of the situation do not as yet make artificial drying feasible. And drying of the moss is necessary for its storage, utilization and economical transportation.

The labor supply is a governing factor in some areas where the gathering of moss is an off-season vocation. Lobstermen frequently gather moss when the lobsters are molting, the intensity of their efforts being determined by the relative prices of lobsters and moss. Gathering moss provides summer employment to college students, and farmers close to the shore find that an extra penny can be earned between haying and harvesting.

Drying and Bleaching

Extensive, flat, clean areas on which to spread the moss are required for drying. These may be sand beaches, cut over hay fields or boarded or cemented areas. At one location flakes are employed. Occasional turning and breaking of clumps is required for thorough drying which may take one to three days, depending on weather conditions. Moss which is gathered in as soon as dried is known as "black moss" because of the dark color of the concentrated red pigment in the frond.

Drying the moss reduces the moisture content from 85% to approximately 20% and the weight to approximately one-fifth of the original. The market value of the moss at this stage is six to eight cents per pound, the lower figures being paid for cast or drift moss.

If the moss is rewetted and exposed to the sun, the red and green pigments are bleached, leaving the moss a yellow or straw color. Some of this bleaching occurs during the initial drying so that commercial black moss always contains a considerable quantity of bleached fronds. For complete bleaching, occasional turning of the moss is required to expose all surfaces to the sun. The time honored practice is to depend on dew or light rains for the required moisture, but two systems are now in operation where the moss is kept thoroughly wet. In this manner a bleaching that normally takes several days is accomplished in one afternoon. One system uses shallow tanks in which the moss is submerged, the other keeps the moss wet with lawn sprays. Because of the care and time consumed and the risk of having the moss spoiled by "bleeding", due to being caught in heavy rains, the price of bleached moss is double that of black moss, or 12 to 16 cents per pound.

If the salt content of the moss is decreased to any considerable extent by bleaching, due to heavy rains or other sources of fresh water, the dissolving temperature of the moss hydrocolloid is lowered and "bleeding" results. Since it is necessary to keep moss wet while bleaching, precautions must be taken to prevent loss of salt in this operation. The use of fresh water is preferable, however, for washing moss to be dried black, since the reduction in salt decreases undesirable weight and facilitates subsequent processing.

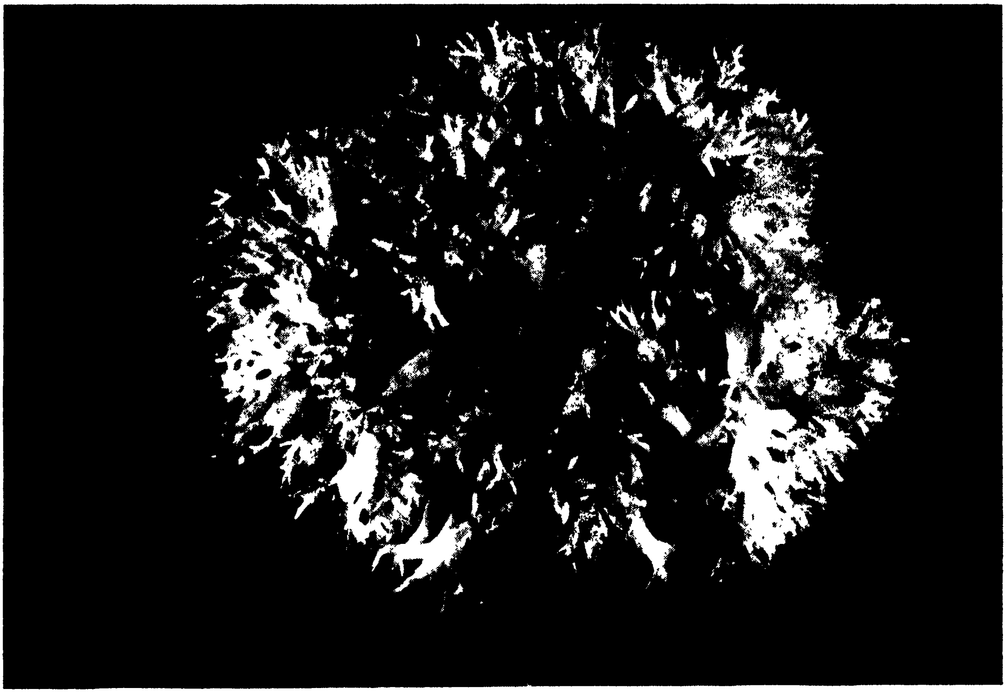
As a rule, bleached moss is more free of extraneous materials than black moss, since foreign weeds and other matter present as contaminants do not bleach and are easily distinguished in sorting operations while the moss is spread out. Black moss can be more easily picked over before it is dried. Floating the seaweed in water facilitates this operation and also washes the moss. This latter practice has not yet become widespread.

At the present time the above methods are sufficient to supply the industry, but experiments with gathering machines are in progress, looking forward to the times when these methods will not suffice. Progress is also being made in devising procedures for eliminating unwanted impurities such as foreign seaweeds and crustacea from commercial Irish moss. This progress will be hastened by quality standards which have been installed this year on a voluntary basis by the Canadian Department of Fisheries. Experiments have indicated that the presence of foreign weeds is the greatest single deterrent to high quality in the final extractive.

Finding sufficient growth of *Chondrus crispus* is not yet a problem, but it is not too early to start a survey of our coastal resources to insure a continuing supply of raw material for an expanding industry.

Extraction

Difficulties in obtaining the extractive from Irish moss may heretofore have prevented wider utilization of this seaweed, although recovery of the hydrocolloid involves fundamentally simple unit processes. The moss is first washed in cold water, then extracted with hot water. The solution of water extractables is clarified by centrifuging and filtering, and may be further purified by treatment with activated carbon. The solids are recovered by driving off the water in evaporators and on drum dryers. A more costly variation of solids recovery involves precipitation of the hydrocolloid with alcohol prior to tray drying. Carrying out these unit processes is more easily said than done, since the very properties that make the extractive so valuable work against easy application of each process. The viscosity and suspending power of the extract require working at high dilution. The particles to be removed are gelatinous so that filtration is difficult, and their composition is 95% water, making centrifuging also inadequate. The logarithmic increase of viscosity with concentration sets a high limit of approximately 2.5% on concentration by evaporation, leaving a relatively dilute solu-



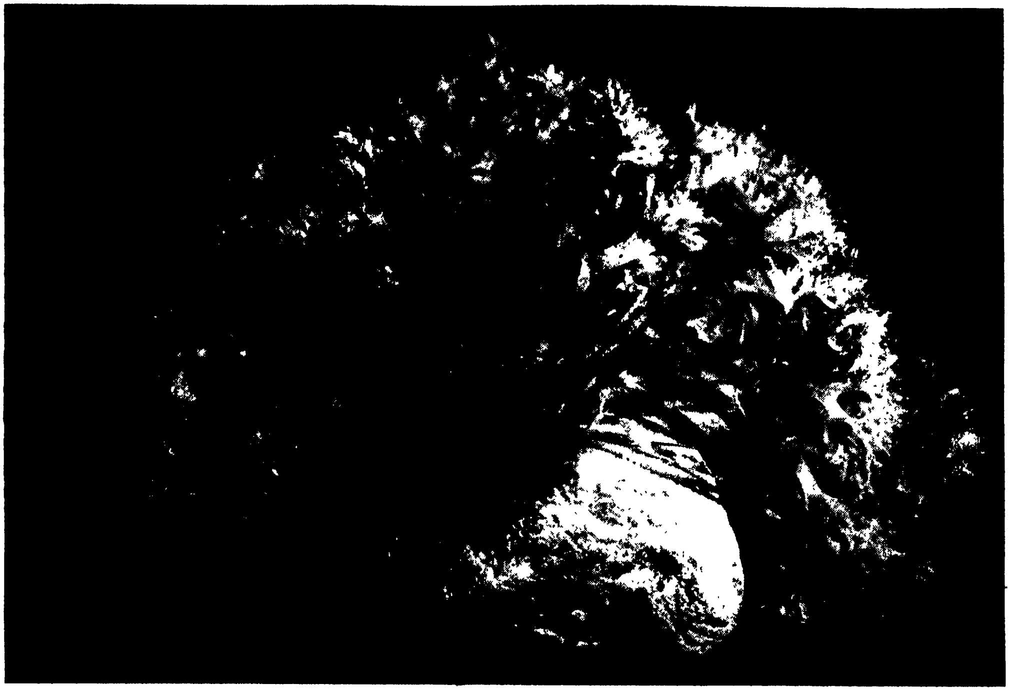


Fig. 1 (*Upper*). A single branching frond of Irish moss. (*Courtesy E. L. Patch Co.*).
Fig. 2 (*Lower*). A clump of branching fronds of Irish moss attached to a rock.

tion to be dried on the drum dryers. All this processing must be accomplished on a material susceptible to hydrolytic and oxidative decomposition. The final product is a feather-weight buff-colored powder which absorbs water rapidly to form a viscous solution at low concentration.

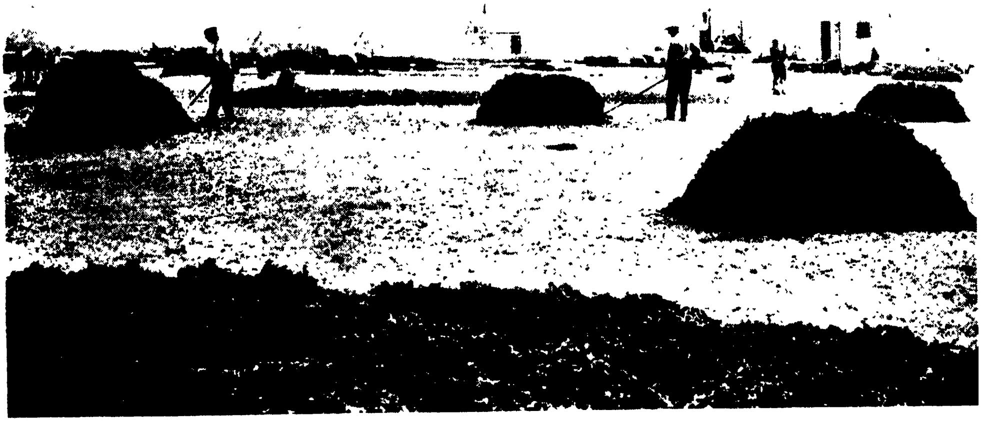


Fig. 3 (*Upper*). Gathering Irish moss by means of long-handled rakes from submerged rocks near the shore at Scituate, Mass.

Fig. 4 (*Lower*). Irish moss spread for drying and raked into piles on the shore at Scituate, Mass.

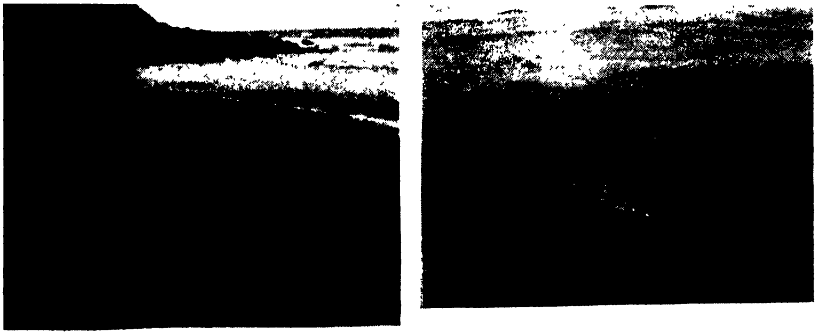
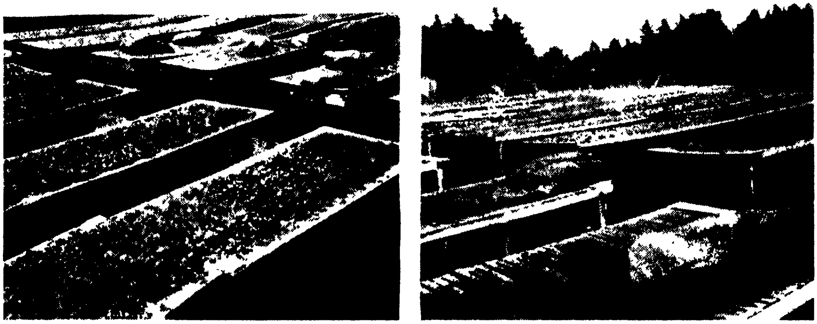
Utilization

The viscosity of the final product is pleasant to both the palate and the skin. Its emollient properties make it useful in such products as hand lotions and cough syrups. It is an excellent emulsifying and suspending agent, being used for medicinal, flavoring and industrial emulsions and suspensions. When appropriate salts are added, it forms thermally reversible gels, dependent on the salt concentrations for their strength and setting temperature. It reacts with proteins to form suspending or gelling systems, as in milk, or fining systems, as in beer.

Other properties of Irish moss extractive, such as its ability to form films, its value as an antioxidant and its general value as a protective colloid, are now under investigation.

To suspend cocoa in milk, approximately 0.04 per cent of extractive will react with milk proteins at 160°F. to form a suspending system when cooled. This reaction also gives a desirable body to the milk. Approximately 0.5 per cent in milk will form a very palatable gel when heated and cooled. This reaction is the basis of the old blanc mange puddings and also of a modern line of flavored powders for making milk puddings. In fact, such utilization of the extractive is a major industrial outlet.

When 15 to 20 pounds of a good grade of Irish moss is added to a 500-barrel kettle of beer wort, the extractive reacts with the proteins in the hot wort, accelerating their coagulation. The coagulated proteins settle out, carrying insoluble fines with them. On cooling the wort, more insoluble particles form, which, if allowed to remain in suspension, would tend to smother the yeast and produce hazy beer. Irish moss in the brew causes a second protein coagulation on cooling to 60° F., the so called "cold break", which carries along all suspended particles, leaving a clear wort on which the yeast may work.



Figs. 5 & 6 (*Upper*). Irish moss cast upon the shore at Prince Edward Island.
Figs. 7 & 8 (*Lower*). Irish moss being sprayed and bleached at Prince Edward Island.

Many frozen foods, particularly those containing fats, are subject to oxidative changes resulting in a rancid, unpalatable and unsightly product. Ascorbic acid has been found to be an effective agent to retard these changes. When ascorbic acid is dissolved in a solution of Irish moss extractive (0.3% ascorbic acid in 0.5% extractive), a solution is produced which forms a continuous film of appreciable depth over foodstuffs dipped therein. Protection of the foodstuff is achieved through an actual physical barrier to oxygen, through emulsification of fats and oils, thus preventing their release to contact with air and to a reinforced antioxidant system due to a synergistic relationship between the ascorbic acid and a natural antioxidant in the extractive.

The baker uses Irish moss extractive in his piping jellies, in his pie fillings and in his icings and meringues. He may soon be using it as a conditioner in his breads and cakes. Piping jellies made with Irish moss extractive are smooth and clean tasting; pie fillings have a short, tender texture; icings remain creamy and moist, yet do not adhere to the wrapper; and meringues are short, tender and stable.

Your favorite toothpaste may contain Irish moss extractive to obtain its uniform smooth body and stable foam. If you are constipated, your mineral oil emulsion will have Irish moss extractive as a base. For a sore throat or chapped hands, the same soothing emollient that the fisher folk found useful in spring cures and hand washes will be effective.

Among the many users of Irish moss extractive are those who know it from family recipes and remedies. Yet even this short exposition will reveal uses new to the old timers. Many more useful properties are still waiting to be explored. It is the attainment of this phase of application research that insures Irish moss its position as a raw material for an American industry.

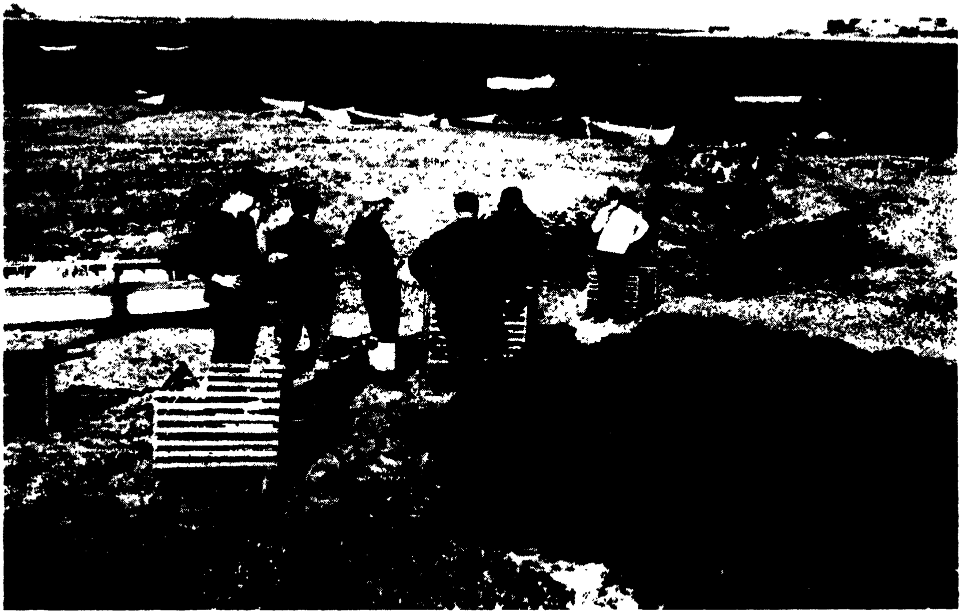
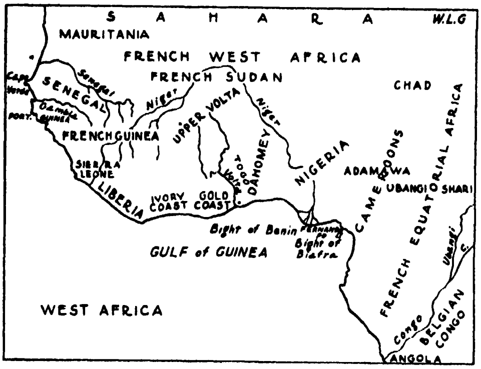


Fig. 9. An Irish moss "exchange" at Scituate, Mass., where the moss, brought to the shore in dories from the gathering beds in shallow water, is sold to representatives of processing firms. (*Courtesy Thomas Dwyer*).

Utilization Abstracts

Indigenous Food Plants of West Africa. Today food plants most commonly used by West Africans are of American or Asiatic origin, namely, cassava (*Manihot esculenta*), groundnuts (peanuts) (*Arachis hypogea*), plantains (*Musa paradisiaca*), maize (*Zea Mays*), bananas (*Musa sapientum*), pineapples (*Ananas comosus*), papayas (*Carica Papaya*), sweet potatoes (*Ipomoea Batatas*) and citrus fruits(*Citrus* spp.). In addition, there are two kinds of coco-yam. One of them (*Xanthosoma*), known as "tannia", is of American origin; the other (*Colocasia*) is native to India and is known in Trinidad as "eddo" or "dasheen"; in Polynesia as "taro". Its common name of "koko" in West African vernacular was originally derived from a Creole (Sierra Leone) imitation of its Portuguese name "curcas".



Before these sources of food were introduced into West Africa, however, the Africans subsisted, so far as vegetable food was concerned, on local plants, and these are still used, both wild and cultivated. Among them are the following:

EDIBLE FRUITS AND SEEDS

Balanites aegyptiaca. (Simarubaceae). Desert date. Kernels of the desert date, which occurs in dry regions where inundations occasionally moisten the ground, are valuable as food and are sometimes used in making a kind of bread, or they may be eaten in soup by the Shawa Arabs. They also provide an edible oil (over 40% of the seed).

Blighia sapida. (Sapindaceae). Akee apple. The oily yellow aril of the fruit is eaten raw or in soup, or fried in oil or butter, or roasted and eaten as a sweetmeat. Named after the famous captain of H.M.S. Bounty. The dangerous properties of the bitter fibrous raphe attached to the aril have long been known in West Africa. The tree is also grown elsewhere, particularly in the West Indies where its name "akee" closely resembles its Gold Coast vernacular name, pronounced "achee", from which it is probably derived. Although the fruit has been commonly eaten in Jamaica, it was a long time before cases of death resulting from vomiting sickness were traced to akee poisoning, due to eating the poisonous portion. The pulp of the fruit itself is edible.

Butyrospermum Parkii. (Sapotaceae). Shea butter-tree. The kernels of the fruits are rich in fat (broker's standard 48%). This fat, called "shea butter" is prepared locally by women and is commonly seen in markets. It is used in African cookery and for other purposes. Generally only the kernels are exported; "shea oil" is extracted from them and made into vegetable butter and other products. However, locally prepared shea butter itself is sometimes carried to other countries. There are probably more than 17 million shea butter trees in French West Africa alone, and the fruits are practically everywhere harvested from trees in a semi-wild condition.

Carissa edulis. The paired purplish-black berries are sweet and edible.

Ceratotheca sesamoides. (Pedaliaceae). This species, closely related to *Sesamum,* is often found wild but is also cultivated. Both leaves and seeds are eaten in soups. The seeds contain 37.3% of oil.

Chrysophyllum spp. (Sapotaceae). Several species used, the pulp of the fruits being the portion eaten in the same way as the introduced star apple, *C. Camito.*

Cola acuminata and *C. nitida.* (Sterculiaceae). Kola. These are probably the most important of several cultivated species of the genus in West Africa, the fruits of which provide a flavoring for beverages in other lands as well as being used as a stimulant in Africa. Kola nuts have been used in Africa since remote times, and there was early trade in them from rain forest regions to the drier regions south of the Sahara. When Leo Africanus first described them in 1556, he aroused a European desire to discover their source. Later, slaves carried the seeds to the New World, and in the 17th century certain Europeans, reaching the West Indies, suddenly discovered the kola tree growing there. Thus for a long time they believed that it was native to that region. These seeds and those of *Aframomum* are the two most important of the very few indigenous West African plants that so far have attracted sufficient attention outside Africa to have resulted in their export.

Cordia Myxa. (Boraginaceae). Assyrian plum, Sapistan. Often specially planted at the edge of the forest by residents of villages or naturalized there. The sticky mucilaginous pulp and the kernels of the fruit are both edible.

Diospyos mespiliformis. (Ebenaceae). West African ebony. The sweet pulp of the fruit, either fresh or dried, is eaten or is sometimes fermented to make a drink. Mixed with dates, figs, *etc.*, a kind of sweetmeat is also prepared from it.

Elaeis guineensis. (Palmaceae). Oil palm. The main oil-producing palm in West Africa, yielding a red oil from the outer layer of the fruit. This is greatly used in African cookery, as well as in world commerce—for example, in margarine manufacture—while from the kernels another oil, known as "palm kernel oil", is obtained. Kernel oil is used by West Africans as a pomade for the skin, as hair oil and as a cooking fat, while in world trade it also has various uses.

Irvingia gabonensis. (Simarubaceae). African mango, Dika nut. Cultivated in lower Dahomey, a variety with a thick edible pulp being sold in the markets in Porto Novo. From the kernels, which contain 54% to 67% of fatty matter, an almost solid, white or pale yellow fat known as "dika butter" is extracted. This has been tried out experimentally in Europe in margarine manufacture and as a substitute and adulterant for cocoa butter. For local consumption the kernels are dried and split into two cotyledons, ground, heated, smoked and made into cylindrical masses known as "dika bread" or "Gaboon chocolate", to be eaten as a seasoner with meat, fish or other dishes. In Gaboon two other food preparations are made from the kernels.

Landolphia spp. Vine rubber. The fruits of various species are edible, those of *L. senegalensis* being sold in markets.

Parkia filicoidea. (Leguminosae). West African locust bean. The seeds are boiled for 24 hours, then pounded, cleaned and boiled to form a paste which is then allowed to ferment for two or three days. They are then made into sticky blackish balls, well known in West Africa where the intinerant Hausa traders barter them under the Hausa name "daudawa". They keep well and are very rich in protein and contain also about 17% of a semi-solid fat. Highly nutritious, they take the place, in some ways, of cheese in a European diet, or are used as a basis for soups and as a seasoner. In addition, the yellow powdery pulp in the pods is dried and sold as meal or made into cakes or blocks which likewise keep well. This is a valuable food which is put into soup or eaten with other foodstuffs. Approximately half of it is composed of easily assimilated sugars.

Sarcocephalus esculentus. (Rubiaceae). Guinea, or African, peach. Fruits are either eaten fresh or dried for future consumption and contain many small seeds.

Sesamum indicum. (Pedaliaceae). This widely distributed plant was probably originally tropical African, for it was known in ancient Egypt about the year 1300 B.C. It is now widely distributed in tropical and sub-tropical regions as "gingelly", "til" or "sesame" in the eastern tropics, and as "beniseed" in West Africa. The latter name originated in Bambara and Malinke (French West Africa). In West Africa it is grown in pure stands, being mainly cultivated for its seeds which are rich in oil. They are used in the form of porridge or as thickening in soup after pounding and washing, or are made into cakes fried with salt, pepper, *etc.* for use on journeys. The young leaves are also added to soups. Beniseed is exported from northern Nigeria, the oil (50% in seed) being used in margarine manufacture and as a salad oil (olive oil substitute) or in its lower grades for soap-making. The residue is useful as a cattle cake.

S. radiatum. This species is generally found growing wild, but is sometimes specially cultivated.

Strychnos spinosa. (Loganiaceae). Kaffir orange. The yellow brown pleasantly acid pulp is edible.

Spondias Mombin. (Anacardiaceae). Hog plum. Fruits sometimes stewed.

Synsepalum (*Sideroxylon*) *dulcificum.* (Sapotaceae). Miraculous berries. A shrub or small tree which occurs wild in West Africa but is often specially planted. The pulp around the seeds causes a persisting sensation of sweetness on the tongue, so that even the acidity of lime juice can not be recognized, nor the bitterness of quinine. These curious effects may last sometimes as long as one or two hours or even longer. Africans use the pulp with certain acid fruits and with palm wine, and to sweeten other foods and even to disguise the taste of stale food.

Tamarindus indica. (Leguminosae). Tamarind. Probably originally African. The pulp around the seeds is edible.

Thaumatococcus Danielli. (Marantaceae). Miraculous berries. A tall forest herb from which the soft jelly-like arils of the fruit provide a lingering sweetness of taste similar to the fruit of *Synsepalum.*

Vitex Cienkowski. (Verbenaceae). West African plum. A black fruit with considerable nutritive value, said to counteract A and B avitaminosis, especially in children.

Zizyphus Spina-Christi. (Rhamnaceae). Christ's thorn. Specially planted for its shade and its edible fruits. Probably the 'lotus' of the ancients.

COOKED FRUITS AND THE LIKE

Citrullus vulgaris. (Cucurbitaceae). Watermelon. The watermelon is of African origin and has been traced back to the fourth Egyptian dynasty. Some varieties are bitter, but others are comparatively sweet and may be eaten either raw or cooked in soup. The seeds, known as "egusi", are dried in the sun, the husks are removed and the kernels are then roasted and ground and put into soup or used as an ingredient in a sauce. They are of good food value (roughly 45% fat and 34% protein), and the oil in them is suitable for cooking. Sometimes the kernels are fermented by the Yorubas of Nigeria to form a food or flavoring called "ogiri". Another food is made from roasted and pounded seeds which are wrapped in a leaf and boiled. Sometimes they are fried in oil, with red pepper (*Capsicum*) added. Watermelons can grow on quite poor soils and with little rainfall. In tropical South African deserts, such as the Kalahari Desert, they provide a food and source of water for primitive tribes. They are also eaten by the antelopes in such regions.

Cucumeropsis edulis and *C. Mannii.* (Cucurbitaceae). Cultivated chiefly for their white oily seeds which are parched and eaten or, like those of the watermelon, pounded and added to food.

Cucumis Melo. (Cucurbitaceae). Melon. The common melon, though of uncertain origin, is probably spontaneous from West Africa to India without interruption. Several varieties are cultivated, some of which are cooked and eaten before ripening, whereas of others only the seeds are eaten.

Gossypium sp. (Malvaceae). Cotton. Cottonseed oil is used in cookery. The Hausas make fermented cakes from the seeds which are edible.

Hibiscus esculentus. (Malvaceae). Okro, Okra. Okra is believed by De Candolle to be of undoubted African origin. Marcgraf, who saw it in Brazil, quotes its Congo and Angola name, "quillobo", which was corrupted by the Portuguese to "quingombo"—hence the name "gumbo" given to the plant in the United States. The plant was cultivated by the Egyptians long before the discovery of America, and Schweinfurth saw it growing wild in the Anglo-Egyptian Sudan and in Abyssinia. It is now widely grown in the tropics. Several varieties occur in West Africa where the fresh, dried and sliced or powdered fruits, and even the dried flowers, are used as a soup vegetable, and the leaves as a pot-herb.

H. Sabdariffa. Roselle, Sorrel. Known in Sierra Leone as "sour-sour" because of its acid flavor, this is a native of either tropical Africa or America, but probably the former. Today it is grown throughout the tropics. After the flower has faded, the fleshy red, yellow or green calyx and epicalyx, which contain malic acid, are used in soup, either in a fresh or a dried state, or are used as a sauce or relish. Europeans have used the calyx for making jelly, chutney, jam, syrup and wine. The seeds are edible, being pounded into a meal and used either as an oily soup or roasted and made into sauce. They are sometimes parched, pounded, and the oil extracted, the residue being put into soup or made into cakes with beans and other foodstuffs. The seeds are further made into fermented cakes, much the same as the widely used daudawa *(Parkia filicoidea)*, described above, in those regions where the locust-bean is scarce. The leaves of the sorrel are also edible. [*H. Sabdariffa* is the source of the commercial fiber roselle which has been extensively discussed in ECONOMIC BOTANY **3**: 89–103, 1949.]

Hyptis specigera. (Labiatae). Sometimes cultivated like beniseed (*Sesamum*), its blackish seeds rich in oil being used as food in the same way.

Lagenaria vulgaris. (Cucurbitaceae). Bottle gourd. The bottle gourd is almost certainly of African origin. Although it is generally cultivated only for its bottle-shaped gourds and calabashes, the fruits being generally too bitter to eat except when very young, certain improved varieties, especially the tubercled form, may be as good as the pumpkin. The young shoots and leaves are also used as a vegetable, and from the seeds of some forms an oil is obtained which is used in African cookery.

Pachylobus edulis. (Burseraceae). Bush butter tree. Specially grown from seeds and cuttings for the sake of its fruits, the outer portion of which is eaten, either roasted or boiled. It can be used as a dessert fruit or eaten with curries.

Polygala butyracea. (Polygalaceae). Probably a relic of ancient native culture. It is grown on a small scale in the Benue region in Nigeria and also on the boundary of Nigeria and Cameroon, Dahomey, Togo and Sierra Leone (Adamawa), and also in a few localities in French and Portuguese Guinea. The solid fat obtained from the seeds is used by some tribes in cooking, but in parts of French Guinea and in Adamawa the seeds are parched, ground up, and added to soup. The method of preparation resembles that used for making ground-nut paste (peanut butter), except that it is more dry and powdery. It has a pleasant nutty flavour and is made up into balls with meat and other foods and cooked with palm oil and spices. The plants can be grown on poor soils and may be a useful addition to local food supplies. It is also grown locally for its fibre.

Sesbania pachycarpa. (Leguminosae). Sometimes grown around villages in upper French Guinea for the sake of the seeds, from which a fermented extract is prepared as a substitute for those of *Parkia.* The seeds of *S. punctata* can be used in the same way.

Solanum anomalum. (Solanaceae). Fruits dried for future use as a condiment. The bitter fruits of *S. aethiopicum, S. duplosinuatum* and *S. nodiflorum* are cooked and eaten.

S. incanum. Garden egg, Brinjal. Fruit edible only after cooking. Though a native of southeast Asia, it has probably been grown in West Africa for centuries, for it has numerous vernacular names there.

S. macrocarpon. Cultivated near houses, especially in forest country, for its leaves and fruits, the latter being edible after cooking.

Telfairia occidentalis. (Cucurbitaceae). Fluted pumpkin. A native of West Tropical Africa where, in the opinion of Dalziel, it probably owes some of its extension, such as at the edge of forests, to its persistence after previous cultivation. The fruits, which are often very large and covered with a waxy bloom, contain a number of large seeds. The cotyledons, which have a pleasant almond-like flavour, are the edible portion, being put into soup or cooked and eaten like beans. The seeds contain an oil used in African cookery, and the young shoots and leaves are used as a potherb. A related species, *T. pedata*, has similar properties, and its seeds are roasted and eaten in Gaboon, the seedcoats being removed and the kernels pounded into a paste, mixed with fish, and then cooked in a banana leaf. The seeds contain an oil. This plant is apparently better known in East Africa and the Mascarene Islands than in its original West African home. [According to C. H. W., editor of the Journal quoted, seeds of *Telfairia pedata* were imported at the time of the World's Fair in New York, 1939–1940, and sold in one or more markets].

EDIBLE LEGUMES

Kerstingiella geocarpa. 'Geocarpa' Groundnut. One of the two groundnuts native to West Africa (see also *Voandzeia*), both of which are cultivated as field crops there, though they are not well known outside of the region. Like the peanut *(Arachis),* they bury their pods beneath the soil as they ripen. The seeds are of high food value, although their yield is poor and they are liable to weevil attack. *Kerstingiella* has a restricted range in West Africa.

Parkia filicoidea. West African locust bean. Discussed above.

Vigna unguiculata. Cowpea. This is almost certainly of West African origin. There are numerous cultivated West African varieties, but it also occurs in a semi-cultivated and a wild state.

Voandzeia subterranea. Bambara groundnut. The other groundnut native to West Africa (see *Kerstingiella*). It has been found in a wild state in northern Nigeria and Cameroons, but it may not have originated in that exact area. There are several varieties. Its oil and albuminoid content is comparatively low, although it is a good all-round human food.

FOLIAGE CROPS

Amaranthus caudutus. (Amaranthaceae). A semi-cultivated plant with edible leaves. According to Dalziel, it was introduced from Asia, but Burkill says it has been used in many parts of Africa as a spinach plant, as well as being widely cultivated in both Africa and the Himalayas. According to Dalziel, it is cultivated in West Africa as a grain crop because of its edible seeds, as in India and elsewhere, *e.g.,* as 'Inca wheat' in Peru. Its country of origin is uncertain, but it appears to have wider cultivation in Africa than in Asia where *A. paniculatus* has a greater extension.

Brassica juncea. (Cruciferae). Indian mustard. Though widely distributed in the tropics, it is believed by Burkill to be of possible African origin. In the East it is cultivated as a condiment and for the oil of its seeds, while the young leaves are used as a vegetable, much like mustard greens in other countries. In West Africa its cultivation for use as a potherb and as a peppery-tasting condiment is reported from the Upper Niger and from Sierra Leone.

Gynura cernua. (Compositae). Sometimes grown as a mucilaginous potherb or used for soups or sauces.

Hibiscus cannabinus. (Malvaceae). Leaves are eaten in soup or as potherb. [This species is the source of the commercial fiber kenaf which has been extensively discussed in ECONOMIC BOTANY **1**: 334–352. 1948].

Hibiscus Abelmoschus. (Malvaceae). Musk-mallow. Leaves and young shoots are sometimes eaten in soup. The leaves of okra *(H. esculentus)* and sorrel *(H. Sabdariffa)* are also eaten.

Lactuca taraxacifolia. (Compositae). Sometimes cultivated and the leaves eaten fresh or cooked. They are sometimes sold in markets as balls of cooked or soaked leaves prepared for use in soups or sauces.

Ocimum viride. (Labiatae). Tea-bush. The leaves of this and of *O. americanum* are used in salads in Calabar and the latter in soup in northern Nigeria.

Senecio Biafrae. (Compositae). The leaves of a cultivated form, probably in several varieties, are said to have been used as a vegetable.

CEREALS

Among the most important indigenous food plants of West Africa are the cereals, particularly Guinea corn (*Sorghum* spp.) and bulrush millet (*Pennisetum* spp.).

Digitaria exilis. Hungry rice. Sometimes cultivated in northern parts of Nigeria, Togo and Sierra Leone, and in Portuguese Guinea and Gambia. The very small grains are used as porridge, or they are parched and ground and mixed with meal of other cereals.

D. Iburua. A small white grain sometimes cultivated around Zaria in northern Nigeria and at Zinder.

Eleusine corocana. Finger Millet. Cultivated in northern Nigeria as food and for malt.

Hordeum vulgare var. *hexastichon.* The only cultivated West African variety of barley.

Oryza glaberrima. One of two local species of rice that are grown, being cultivated inland and from French Sudan to northern Nigeria.

Oryza Stapfi. Another local species of rice, being cultivated in Gambia where it is regarded as the original rice, since it is hardier than any other form.

Penisetum spp. Bulrush millet. Eight local species in cultivation, being generally grown in western Sudan and northern Nigeria. These species are *P. anchylochaete, P. cineereum, P. gambiense, P. gibbosum; P. leonis, P. maiwa, P. nigritarum* and *P. pycnostachyon.*

Sorghum spp. Guinea corn. Twelve species are grown in the dry northern areas: *S. aterrimum* (E. Sudan), *S. caudatum* var. *colorans* (as a dye), *S. cernuum* var. *officulatum* (Gambia and Fr. Sudan), *S. durra* var. *niloticum* (in alluvial soils), *S. exsertum* var. *amplum* (N. Nigeria) (also sometimes used to dip leather), *S. gambicum* (Gambia and Fr. Sudan), *S. guineënse* var. *involutum* (Togo to N. Nigeria), *S. margaritiferum* (best known in western area), *S. membranaceum* var. *Baldratianum* (soft sweet variety) (N. Nigeria), *S. notabile* var. *notabile* (N. Nigeria). There are two sweet sorghums from which molasses or sweetmeats can be prepared or the stems chewed.

Triticum spp. Two species of wheat are native to West Africa, an awnless, soft wheat, *T. vulgare* var. *leucospermum,* being grown in parts of northern Nigeria as a wet season crop or under irrigation in the dry season, mainly by the well-to-do, while a macaroni wheat, *T. durum* var. *leucurum,* is commonly cultivated in northern Nigeria. Chevalier states that the soft wheat predominates. Both are used as food, either made into wheaten cakes, boiled in oil and seasoned, or into buns, or finely ground with butter, or even made into a form of macaroni called "taliya" by the Hausas.

ROOT CROPS

Coleus dazo. (Labiatae). Has tuberous roots, and its stems become woody and may be two or more feet in height. Although it occurs wild as well as cultivated in both West and Central Africa to as far south as Natal, its exact original home is unknown. It is grown chiefly in the Zaria province of northern Nigeria, but also on the upper Ivory Coast and on a large scale in upper Ubangi-Shari (under the name of "dazo") and in the lower Congo. The softly hairy and cylindrical tubers are generally up to four inches long and ¾ inch in diameter, in composition similar to the ordinary potato. They are more difficult to propagate than the Hausa potato *(C. dysentericus),* and are generally grown from tubers which require up to six months to mature after planting, although in equatorial regions tubers can be obtained almost throughout the year. Under proper cultivation it is probably possible to get larger yields from this species than from any other Labiatae. It is believed that the so-called Kaffir potato *(Plectranthus esculentus)* also belongs to this species.

C. dysentericus. The Hausa or Sudan potato, sometimes known as the "Madagascar potato" (of French colonists), is widely grown in drier parts of tropical Africa and elsewhere, and is believed by Heckel to be of Abyssinian origin. It is cultivated for its edible tubers in western Sudan, Ubangi-Shari and the Congo Basin, and is grown preferably on mounds or broad ridges by the Hausas of northern Nigeria. Numerous small tubers are produced; some varieties have reddish-grey or reddish-yellow, others blackish-brown, and others greyish-white tubers. It is propagated by soft-wood cuttings and by tubers which take five to six months to mature. According to Barter, they are used in cases of dysentery by the Yorubas for dietetic rather than medicinal reasons. In hot climates they are regarded as a most suitable substitute for potatoes. The plant is sometimes grown under irrigation in the dry season, in the same way as onions, wheat and other crops.

Dioscorea alata. (Dioscoreaceae). The Water Yam, now widely grown in West Africa, where it has many varieties, was, in Burkill's opinion, originally Asiatic. Because it carried well, with little sprouting, it was taken to East Africa and Madagascar and thus was spread, probably by the Portuguese, to other parts of the African coastline and eventually to the new World in slave ships.

D. bulbifera. Bulbil-bearing yam or Potato Yam. The most widely distributed of all species of *Dioscorea,* introduced into America during the slave trade. The liver shaped and flattened bulbils are cooked, whereas the best forms can even be eaten raw. The cultivation of this plant in order to develop larger bulbils has resulted in a comparatively small and generally inedible terrestrial tuber being formed. Burkill believes that Africans are still engaged in the process of 'enobling' (cultivating) this species. Its wild forms are generally smaller and more toxic, de Wildeman reporting in 1938 that in one case the eating of the bulbils resulted in the death of 32 soldiers. Toxic forms like this and other poisonous species, such as the three-leaved yam *(D. dumetorum),* are sometimes specially planted along the edges of farms to discourage thieves.

D. cayenensis. Yellow Guinea yam. A crop plant entirely developed by the African himself. Almost certainly it was originally grown in Guinea (hence its English name), and its cultivation is most dense there today. It is sometimes called the "twelve months yam", and its long period of growth restricts it to the moister regions. The main tuber is sometimes cut away, after which the top will produce one or more smaller tubers, giving this race (an inferior one) the West Indian name of "cut-and-come-again". This yam and *D. rotundata* were taken to America in the days of the slave trade. Both produce tubers close under the surface of the ground.

D. praehensilis. Bush or Forest yam. The tubers are occasionally eaten or used as a famine food. It is best known as the parent of the cultivated white yam, *D. rotundata.*

D. dumetorum. Although wild forms are known to be poisonous and are even used medicinally or as an arrow poison, cultivated varieties have often been sufficiently improved to be edible. They have lobed or star-shaped tubers, varying from white to yellow. They are easy to grow, yield heavily and are also easy to harvest. The poison is removed by peeling, slicing, pulping and soaking, preferably in running water, otherwise in salt water. A coarse starchy meal is sometimes obtained. The tuber of the cultivated form is mucilaginous and after soaking and cooking is generally eaten sliced. This species sometimes produces aerial bulbils.

D. Preussii. While used mainly as a famine food, the wild tubers are still eaten in some districts, especially by hunters, but only after being thoroughly soaked and the liquid discarded to remove the poison contained in it. When cultivated, this species is used for other purposes.

D. rotundata. White Guinea yam. Also native to Africa with many local varieties. The tubers are white and have better keeping qualities than does the yellow yam *(D. cayenensis).*

D. spp. There are a number of other edible species of yam in West Africa, although certain ones, such as *D. sansibarensis, D. Quartiniana, D. minutiflora, D. smilacifolia, D. praehensilis* and certain wild form of *D. dumetorum* and *D. bulbifera,* deserve to be classed merely as famine foods. Most of them tend to be poisonous unless thoroughly soaked and the liquid discarded.

Sphenostylis stenocarpa. This is the wild yam-bean of West Africa, but it is possible that its country of origin is Abyssinia. Though occasionally found wild, the plant is generally cultivated along with yams and beans. It is also grown in French Equatorial Africa, the Congo Basin and in East Africa. The tuber, in appearance like a small sweet potato, two to three inches long, is starchy and is said to taste like an ordinary potato. The seeds of this bean can also be eaten after preliminary soaking. It is suitable for cultivation elsewhere, being a plant of distinct ornamental value, and can be propagated by tuber or by seed.

SPICES, *etc.*

Aframomum melegueta. The so-called grains of paradise or melegueta pepper, better known nowadays as "Guinea grains", were formerly exported mainly from what is now the Liberian coast. The small grain-like spicy seeds account for the old name, the Grain Coast, now Liberia, given to that part of the coast of Guinea on old maps. Formerly important in European trade as a spice or medicine, today they are used outside Africa mainly in veterinary medicine, domestic (non-official) remedies and certain alcoholic drinks. Africans themselves use them extensively in medicine and as a spice in their food. These seeds and the fruits of *Cola* are the two most important of the very few indigenous West African plants that so far have attracted sufficient attention outside West Africa to have resulted in their exportation.

Ammodaucus leucotrichus. (Umbelliferae). Grown in the upper Niger valley, Mauritania and in Sahara oases for the use of its seeds as a condiment in sauces.

Aeolanthus heliotropoides and *A. pubescens.* (Labiatae). Cultivated for use as a flavoring in soups.

Borassus flabellifer. (Palmaceae). Fan palm. The fresh sap is used as yeast or fermented into vinegar.

Carissa edulis. (Apocynaceae). Fruits fermented into vinegar.

Cissus caesia. (Vitaceae). An acid drink or vinegar is obtained from the black succulent fruits in Sierra Leone.

Irvingia gabonensis. (Simarubaceae). The kernels are used as a seasoning with various local dishes.

Ocimum americanum. (Labiatae). Occurs wild in Africa and Asia, and is not American at all, except by introduction. Its leaves which are strongly fragrant are used as a stuffing for fowl, or may be boiled with meat or in soup.

Solanum anomalum. (Solanaceae). Sometimes cultivated and its red berries used in soups and sauces as a condiment with laxative and digestive properties, being said to restore the appetite of sick persons. They are often dried and preserved and are sometimes mixed with daudawa *(Parkia).*

S. nodiflorum. May occur wild, or is sometimes cultivated, its small black berries being quite bitter when wild and used as a digestive tonic and appetizer for sick persons. When cultivated the fruits are sometimes very sweet and can be eaten either raw or cooked, alone or mixed with other food.

BEVERAGES

From the ground-up seeds of the African breadfruit *(Treculia africana),* a kind of "almond milk" is prepared, while from the fruits of the semi-cultivated hog-plum *(Spondias Mombin),* a refreshing drink can be made. The powdery edible pulp from the fruits of two or three leguminous trees, such as the velvet tamarind *(Dialium guineense)* and the West African locust bean *(Parkia biglobosa)* is macerated in water to make other unfermented beverages. When this *Parkia* is used, honey is sometimes added to make it a soothing drink for children. If another species of West African locust-bean *(Parkia filicoidea)* is used, the drink prepared is sometimes mixed with tamarind water (from *Tamarindus*). The seeds themselves of *P. filicoidea* provide another kind of unfermented drink when ground to a fine meal and mixed with water to make a thin gruel. An attractive beverage is prepared from the macerated fruits of the jujube tree *(Zizyphus jujuba),* and a pleasant drink known as "kango" in Hausa is prepared from the pulp of the desert date *(Balanites aegyptiaca).* From the pulp of the Akee apple *(Blighia sapida)* and from *Vitex cienkowskii* fruits a drink is sometimes prepared, sweetened with sugar cane and flavored with ginger and Guinea grains. A beverage is also prepared from the fleshy calyx of roselle *(Hibiscus Sabdariffa).*

The species of *Coffea* present a curious situation, for about ten kinds of commercially ground useful coffees are native to tropical Africa, some still occurring in the wild state. Of these, five species are native to West Africa—namely, Lagos or Abeokuta coffee (*Coffea Abeokutae*), Liberian coffee *(C. liberica),* Robusta or Rio Nuñez coffee *(C. robusta),* Sierra Leone, Upland, or Stenophylla coffee *(C. stenophylla)* and *C. Maclaudii.* Stenophylla was, according to Dalziel, cultivated in a small way long ago in both French Guinea and Sierra Leone, and was probably grown in French Guinea in early days by the Portuguese. According to Afzelius, Liberian coffee was being cultivated in Sierra Leone in 1792 and has been grown along the West African coastline during the last century. Several other species of *Coffea* of more or less economic interest grow in West Africa. There seems little evidence, however, of the use of coffee as a beverage by West Africans in pre-Portuguese days. The chief coffee plant of the world, and the source of "Brazilian" coffee—that is, Arabian coffee *(C. arabica)*—is a native of the Abyssinian mountains. According to De Can-

[illegible] one, the [illegible] coffee [illegible] ancient in Abyssinia and the berries was probably collected from wild plants for centuries before the plant was cultivated. Its use spread later to Egypt, Persia and Arabia, and so to other parts of the world.

Palms are the source of most of the fermented beverages, chiefly the oil palm *(Elaeis guineensis)*, the *Raphia* palms, the fan palm *(Borassus flabellifer)* and even the small wild date palm *(Phoenix reclinata)*. The trees are tapped as they stand, but on the Gold Coast in particular the oil palm is first cut down, then an incision made in the trunk and the wine is collected daily. It resembles ginger beer at first, but becomes increasingly intoxicating later. In parts of West Africa palm wine is used instead of commercial yeast in bread-making.

The fruits of several dicotyledonous trees are also used in the preparation of fermented beverages, examples being the black plum *(Vitex Cienkowskii)*, *V. grandifolia,* West African ebony *(Diospyros mespiliformis)*, *Lannea acida,* desert date *(Balanites aegyptiaca)* and two vine rubbers (woody climbers) *(Landolphia Heudelotii* and *L. owariensis)*. The seeds of cultivated indigenous cereals, such as Guinea corn *(Sorghum)* and bulrush millet *(Pennisetum)* are frequently made into fermented drinks.

SWEETMEATS

In Africa sweetmeats are probably much less common than in other regions—India for example. West African peoples, however, do make sweets from extracts of fruit pulps of certain trees, such as the 'tallow tree' *(Detarium senegalense)*, West African ebony *(Diospyros mespiliformis)*, *Cordia abyssinica, Vitex grandifolia* and black plum. *V. Cienkowskii,* honey being added in some cases. Although sugar- cane *(Saccharum officinarum)* is grown, it is not native, and the canes are generally only chewed. Molasses is made, however, from the stems of two species of sweet sorghum *(S. mellitum* var. *mellitum* and *S. nigricans* var. *peruvianum)*. The molasses is also used in making sweetmeats called "alewa" in Hausa, a word of Asiatic origin. The Hausas make at least three different kinds of sweetmeats. One of [illegible] commonly prepared from tubers of the tiger-nut *(Cyperus esculentus)*, elsewhere known as "earth-almond" or "rush-nut". In certain parts of West Africa the pap made from cereals is sweetened with the fruits of *Cordia abyssinica.*

(F. R. Irvine, *Jour. N. Y. Bot. Garden 49: 225–236, 254–267. 1948.* Except for the alphabetical arrangement of species and minor other changes, the foregoing account is a reprinting of the text in the cited article.)

Tropical Woods. "The School of Forestry at Yale University has been actively engaged in research in the field of tropical woods for more than twenty-five years, during which time it has built up a collection that now contains over 45,000 specimens of wood, mostly tropical in origin. At various times in the past certain woods or groups of woods have been subjected to mechanical and physical tests. In April 1947 the scope of these activities was expanded to meet the growing need for technical data relating to the properties of tropical woods. Under the sponsorship of the Navy Department through the Office of Naval Research, studies were initiated to determine the basic properties of a selected group of tropical American timbers and to evaluate each species with regard to its potentialities for specific types of use".

"The first shipment of logs received under this project arrived in New Haven in April 1947. Since that time nearly 250 logs representing 95 different species have been received. To date, tests to determine the basic physical and mechanical properties of these woods have been conducted on material representing 43 species. Mechanical test data collected thus far are largely limited to the properties of the unseasoned wood. For 25 of these species sufficiently representative data have now been obtained to warrant publication".

Thus reads part of the introduction to this very informative report which contains not only technological data concerning the 25 woods, but also considerable information respecting their common and scientific names, their natural distribution and their uses. (F. D. Dickinson, R. W. Hess, F. R. Wangaard, *Tropical Woods, No. 95. 145 pp. 1949*).

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